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RECOGNITION METHOD OF SPECIFIED TYPES OF SIGNAL MODULATION BASED ON A PROBABILISTIC MODEL IN THE FORM OF A MIXTURE OF DISTRIBUTIONS

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ABSTRACT

Context. The article considers the features of solving non-traditional problems of recognition of specified types modulation signals in automated radio monitoring. The practical features of this problem determine the increased a priori uncertainty, which consists in the absence of a priori information about the distribution densities of the given signals and the presence of unknown signals.

Objective. It is proposed to solve the problem using an unconventional method for the recognition of statistically specified random signals in the presence of a class of unknown signals. This method assumes that for the given signals there is a classified training sample of realizations, according to which the unknown parameters of their distributions are estimated, as well as some threshold values that determine the probabilities of correct recognition of the given types of signal modulation in the presence of unknown signals.

Method. A general solution to the problem of recognition of given signals in the presence of unknown signals is given, and recognition methods of types modulation based on the description of signals by probabilistic model in the form of a mixture of distributions are given. The method is based on the description of signals by a probabilistic model in the form of a mixture of distributions and construction of a closed area for given signals in the probabilistic space of signals.

Results. Studies of the recognition problems of given types of modulation of signals have been carried out. The studies were performed by statistical tests on samples of signals for radio monitoring of communications. In this case, the decisive rule for recognizing the given types of signal modulation is implemented in software on a computer. As a result of the statistical tests carried out on control samples of signals, estimates of the probabilities of correct recognition of the given types of signal modulation in the presence of unknown signals were obtained.

Conclusions. Values of indicators of quality of radio emissions recognition acceptable for the practice of radio monitoring are obtained. The dependences of quality indicators on some conditions and recognition parameters are property. As a result of the research, practical recommendations were obtained on the use of the proposed method for recognizing specified types of signal modulation in automated radio monitoring systems.

KEYWORDS: automated radio monitoring, radio emission, signal, types modulation, probabilistic model, recognition method, statistical tests. the probability of correct recognition.

ABBREVIATIONS

RM is a radio monitoring;
RE is a radio emission;
TM are types of modulation.

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NOMENCLATURE

M is a number of classes of recognizable signals;

$\vec{x}$ is a finite-dimensional random vector of some observations;

L is a dimensions of realizations of the observed signals;

$W(\vec{x}/\vec{\alpha}^i)$ is a probability densities of the signals;

α^i is a vector parameters of the probability densities;

$P(H^i)$ is a priori probabilities of hypotheses;

$\vec{x}_r^i$ is a training sample for the signals;

n_i is a volume of the training samples;

λ is a threshold value in decision rule;

$A_c(k)$, $A_s(k)$) are the quadrature components of the signals;

$\sigma_{c\,j}^2$, $\sigma_{s\,j}^2$, are the variances of the quadrature components;

m_{cj}, m_{sj} are the mathematical expectations of the quadrature components:

g_m are the weight coefficients in a composition of distributions;

Q is a number of components in a composition of distributions;

$P_{(M/M+1)}$ is a average probability of an erroneous decision-making in favor of signals with a given TMs under the action of signals from the (M+1)-th class;

$P_{(M+1/M)}$ is a average probability of an erroneous decision-making in favor of signals from the (M+1)-th class under the action of signals with a given TM;

P_M is a average probability of error due to entanglement of signals within the class of signals with given TMs.

INTRODUCTION

Radio monitoring is a complex task of spatially-spectral-temporal processing of radio emissions in a wide frequency range. To simplify the solution, it is decomposed into a number of relatively independent processing tasks, in particular, detection of radiation sources operating in separate frequency channels, selection and recognition of the given types of radiation sources, recognition of the types of modulation of RE, recognition of species and estimation of modulation parameters for new unknown RE, recognition of RE sources. These processing tasks are solved by signals corresponding to the RE from the output of automated radio monitoring complexes. Therefore, for their mathematical description, mathematical models adequate to the solvable problems of signal processing should be used. It should be noted that due to the action of noise and many other uncontrolled factors, the observed signals are random in nature with a priori unknown statistical characteristics. A priori uncertainty regarding the statistical characteristics of signals is usually overcome by using training samples of signal implementations that can be obtained for given RE. However in case of RM many unknown RE are received for processing, for which it is not possible to obtain training samples of signals. Under such conditions it becomes impossible to use known statistical methods for pattern recognition in automated RM. In classical problems of signal recognition a priori uncertainty overcoming was carried out using training samples of the signals being recognized. However, in real problems of the automated RM, situations arise when the observed signal may not belong to the given classes of signals and should be assigned to the class of unknown signals not specified in the probabilistic sense.

The object of study is the process of solving of recognition signals problems in automated RM.

The subject of study is the non-traditional methods of given signals recognition in the presence of unknown signals when probabilistic models in the form of a mixture of distributions is used to describe of the signals.

The purpose of this work is discusses the features of solving the problem of recognition of the specified TM of signals. Based on this mathematical model of signals, the decisive rule for the recognition of given signals is synthesized. Investigations of the recognizing task specified types modulation of signals by means of statistical tests on samples of the corresponding signals have been performed.

1 PROBLEM STATEMENT

Let us consider the features of the formalized formulation of the signal recognition problem under the indicated conditions for solving recognition problems with the automated RM. We assume that the signals being recognized are represented by finite-dimensional random observation vectors $\vec{x}$, according to the implementation of which decisions are made. The $(M+1)$-ahypotheses are set that can be made with respect to the observed signals: $H^i, i=\overline{1,M}$ – for the specified signals, H^{M+1} – for the unknown signals combined in the $(M+1)$-th class. It is assumed that the probability densities of the distributions of specified signals $W(\vec{x}/\vec{\alpha}), i=\overline{1,M}$ are presented up to random vector parameters $\vec{\alpha}^i$, $i=\overline{1,M}$, and the probability density is unknown for the $(M+1)$-th class of signals. A priori probabilities of hypotheses $P(H^i)=P_i$, are also given, moreover $\sum_{i=1}^{M} P_i = 1.$ It is also believed that training samples $\{\vec{x}_r^i, r=\overline{1,n}; i=\overline{1,M}\}$, for M signals have been obtained and the training sample for the $(M+1)$-th signal is absent or it is not representative.

The nonrandomized decision recognition rule splits the sampled signal space into $(M+1)$ non-intersecting regions, in particular, regions separately for M given signals and the rest of the space – for unknown signals. In accordance with the available a priori information about the signals, it is possible to construct own regions only for given signals.

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2 REVIEW OF THE LITERATURE

Features of different signal processing tasks during automated radio monitoring are considered in [1–3]. In particular, the importance of solving the problems of recognizing RE from the signals representing them is noted. Features of solving the problem of automatic classification of signal modulations during radio monitoring are considered in [1]. Creating the information basis of spectral masks for automated RM are considered in [2]. Methods detection and recognition of signals for RM are considered in [3].

In [4–7] the different methods for automatic recognition of types of modulation for signals is presented. In particular, method of robust automatic signals modulation classification under varying noise conditions are considered in [4]. Method of radar signals modulation recognition based on deep joint learning are considered in [5]. Method of communication signals modulation recognition based on statistical model are considered in [6]. Method of automatic signals modulation recognition using wavelet transform and neural network are considered in [7].

The tasks of recognition signals corresponding to given RE have to be solved under conditions of a priori uncertainty. Since real signals are, generally, random in nature, statistical methods of pattern recognition should be used for signal recognition. These methods are considered in [8–10]. A priori uncertainty is overcome using classified training samples of recognized signals. However, in real problems of the automated RM, situations arise when the observed signal may not belong to the given classes of signals and should be assigned to the class of unknown signals not specified in the probabilistic sense [11].

When solving the problems of signal recognition based on the selected probabilistic model, the presence of unknown signals should be taken into account. In [12] an appropriate signal recognition method based on the autoregressive model was proposed.

From the analysis of publications, it follows the relevance of researching the possibilities of using non-traditional methods of selection and recognition of given random signals to solve problems of recognizing specific types of modulation in automated RM. In this case, it is necessary to specify the methods for recognizing signals by selecting probabilistic signal model that are adequate to the solved of recognizing problems. In addition, studies should be carried out of the proposed methods for signal recognition using signal samples characteristic of the problems of recognition of RE in radio monitoring.

To achieve the goal of research in this article:

– the theoretical features of the methods of recognition of specified types modulation of the signals in the presence of unknown signals based on probabilistic models in the form of a mixture of distributions are considered;

– the values of recognition quality indicators were studied by statistical tests of recognition methods on communication signals samples corresponding to the problems of recognition of given types of modulation in RE.

3 MATERIALS AND METHODS

The solution of the formulated problem of recognizing given signals in the presence of a class of unknown signals can be based on constructing in the sample space closed own regions for *M* signals defined by their training samples of implementations. When realizations of the observed signal fall into one of the signal's own regions, a decision is made about the action of the given signal. Otherwise, a decision is made about the action of the unknown signal. The shape of their own areas is determined by the specific types of signal distribution densities, which depend on the selected probabilistic model for given signals, as well as on predetermined threshold values that are selected from the condition that the specified indicators of signal recognition quality are achieved.

To solve such an unconventional problem of selection and recognition of given signals in the presence of a class of unknown signals, it is advisable to use the following decision rule [11]:

– if inequalities hold

$$\max_{l=\overline{1,M}} \left\{ P_l W\left(\vec{x} / \vec{\alpha}^{\,l} \right) \right\} < \lambda, \tag{1}$$

then H_0 hypothesis about the action of the $(M+1)$-th class of unknown signals is accepted;

– if the system of inequalities holds:

$$\max_{l=\overline{1,M}} \left\{ P_l W\left(\vec{x} / \vec{\alpha}^{\,l} \right) \right\} \geq \lambda, \tag{2}$$

$$P_i W(\vec{x} / \vec{\alpha}^{\,i}) \geq P_l W(\vec{x} / \vec{\alpha}^{\,l}),\ l = \overline{1,M},\ l \neq i, \tag{3}$$

then H^i hypothesis about the action of the specified i-th signal is accepted.

Here, the unknown parameters of the distribution densities α^i are estimated from the training samples for M signals, and the threshold value λ is determined from the condition of ensuring a specified probability of correct recognition of the specified signals.

Note that when constructing the decision rule (1), information on the distribution density of the $(M+1)$-th signal was not used and its training sample was not required. The statement and solution of the considered recognition problem is a formalization of the substantive requirement about the need to isolate (perform selection) and recognize M specified signals and classify unknown signals in the $(M+1)$-th class, information about which is insufficient for their recognition.

When using a probabilistic signal model in the form of a mixture of distributions, the decision recognition rule (1–3) takes the following form [12]:

– if the conditions hold:

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$$\max_{l=1,M}\left\{P_l \sum_{q=1}^{Q} g_m W_m\left(\vec{x}/\vec{\alpha}^l\right)\right\} \geq \lambda, \quad (4)$$

$$P_i \sum_{q=1}^{Q} g_m W_m(\vec{x}/\vec{\alpha}^l) \geq P_l \sum_{q=1}^{Q} g_m W_m(\vec{x}/\vec{\alpha}^l),\ l=\overline{1,M},\ l \neq i, \quad (5)$$

the hypothesis H^i about the action of the i -th given signal is accepted;

– if the conditions hold:

$$\max_{l=1,M}\left\{P_l \sum_{q=1}^{Q} g_m W_m(\vec{x}/\vec{\alpha}^l)\right\} < \lambda, \quad (6)$$

then the hypothesis H^{M+1} about the action of unknown signals from the $(M+1)$ -th class is accepted.

After making a decision to observe the given types of signal modulation, a decision is made according to (5), what kind of signal modulation is observed. In this case, there are probabilities of confusion between the given types of signal modulation.

Under the assumption of independence of samples of quadrature components, the probabilistic properties of signals were determined by mixtures of Gaussian distributions of samples of quadrature components in the form [11]:

$$W(\vec{A}_c) = \sum_{j=1}^{N} \frac{1}{\sigma_{cq}\sqrt{2\pi}}\left[-\frac{(A_{cj}-m_{cj})^2}{2\sigma_{cj}^2}\right],$$

$$W(\vec{A}_s) = \sum_{j=1}^{N} \frac{1}{\sigma_{cq}\sqrt{2\pi}}\left[-\frac{(A_{sj}-m_{sj})^2}{2\sigma_{sj}^2}\right], \quad (7)$$

where $\sigma_{cj}^2, \sigma_{sj}^2, m_{cj}, m_{sj}$ – are respectively, the variances and mathematical expectations of the quadrature components.

At the same time, a special case of the decision-making rule (4–6) on the $2N$-dimensional vector of independent quadrature components of the signals $(A_c(k), A_s(k)),\ k = 0,1,2,\ldots, N-1$ can be used.

In the given decision rules for recognition, it is assumed that for unknown parameters of signal distribution densities there are their estimates calculated from training samples of realizations of the specified signals.

4 EXERIMENTS

Let us consider some results of studies of the problems of recognition of RE, which were carried out by statistical modeling. Moreover, the methods of selection and recognition of random signals in the presence of a class of unknown signals, which are described in clause (4–6) are implemented on a computer program. Next, statistical tests were carried out on samples of implementations of some signals that correspond to RE characteristic of radio monitoring of communications. Based on the training samples of the given signals, the corresponding parameters of the decision rules are calculated. Control samples of signals were used to find estimates of the probabilities of signal recognition based on the results of statistical tests. By changing some conditions and research parameters, the corresponding dependences of signal recognition quality indicators are obtained.

Under the conditions of increasing load of radio bands with automated RM, it is also an important task to recognize the specified types of modulation for the newly detected REs. This is a more difficult recognition problem compared to the above considered problem of recognition of the REs with given types and modulation parameters. The complexity is due to the fact, that whole classes of signals are subject to recognition – signals with a definite TM and various possible values of the modulation parameters. Recognition of TM signals during RM in real conditions is difficult due to the random nature of the transmitted messages, interference action, as well as the appearance of radio signals with new previously unknown TMs for which there is no a priori information.

It is proposed to solve this problem as a problem of recognizing classes of signals with known TMs in the presence of a class of signals with unknown TMs. In this case, the general form of the decision rule for the selection and recognition of given signals (1–3) is concretized taking into account the description of signal classes with given TMs by a probabilistic model in the form of a mixture of distributions (4–6). Here, the decision on the TM is made according to the implementation of the signals in the form of sequences of samples of quadrature components $A_c(k)$, $A_s(k)$, $k = 1, 2, 3, \ldots, N$, obtained from the output of a digital radio receiver. The studies were conducted for signals with the following types of modulation: on-off amplitude modulation (AM2), on-off and four-position frequency modulation (FM2, FM4), and on-off phase modulation (PM2), sixteen-position code-amplitude modulation (QAM16), unmodulated carrier (NON).

When choosing such an initial description of the signals for each specific type of modulation, characteristic images are formed – areas determined by the projections of the readings of the quadrature components $A_c(k)$ and $A_s(k)$ onto the plane with coordinates (A_c, A_s) (Fig. 1).

The signals were observed on the background of interference in the form of Gaussian white noise. It can be seen that these projections define characteristic regions for each type of modulation. Here, histograms of the distribution of the values of the signals quadrature components are given for each coordinate.

5 RESULTS

From an analysis of the content of the problem of recognition of TM signals, it follows that a model in the

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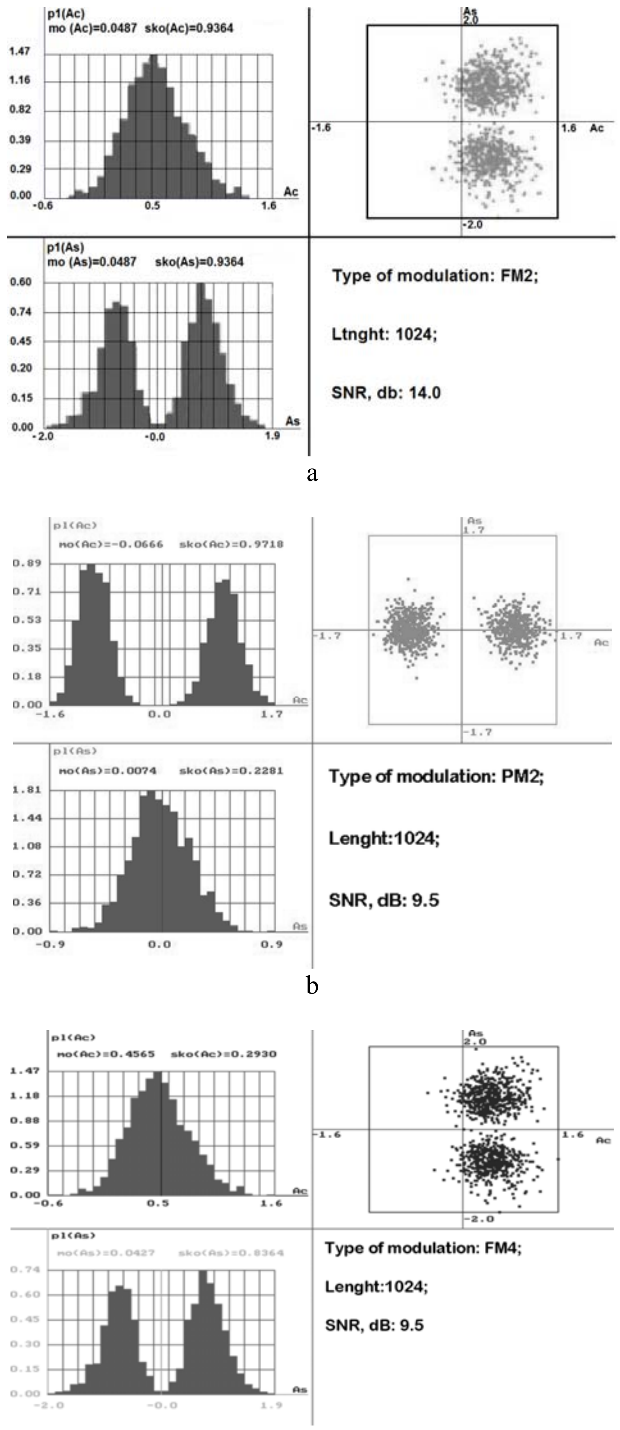
form of a mixture of distributions and the corresponding decision rule (4–6) taking into account relations (7) can serve as a suitable probabilistic model for describing signals with different TMs.

Estimates of the quality of recognition of TMs were obtained by statistical tests on samples of signals with different TMs (Fig. 1) at different values of the



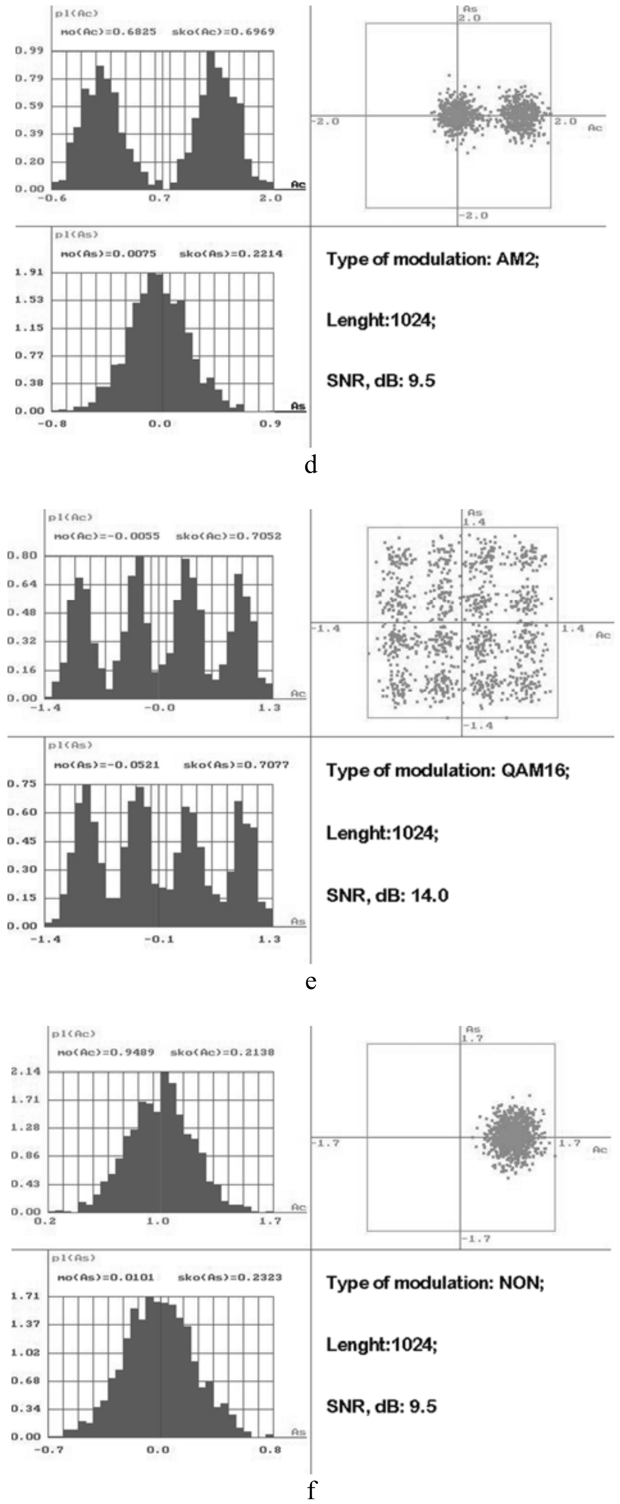


Figure 1 – Histograms of the distributions of the quadrature components of the signal samples with different types of modulation:
a – FM2, b – PM2, c – FM4, d – AM2, e – QAM16, f – NON

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manipulation rate in the range of 100–2400 Baud. For each type of signal, training and control samples of 500 realizations with a length of N = 1024 quadrature samples were obtained. The training samples of signals with given TMs were used to evaluate the unknown parameters of the decision rule for recognizing TMs (4–6). Control samples of signals were used to obtain estimates of the quality of recognition of TMs through statistical tests.

The recognition quality of TM signals was evaluated by the following indicators: $P_{(M/M+1)}$ – the average probability of an erroneous decision-making in favor of signals with a given TMs under the action of signals from the $(M+1)$-th class; $P_{(M+1/M)}$ – the average probability of an erroneous decision-making in favor of signals from the $(M+1)$-th class under the action of signals with a given TM; P_M – the average probability of error due to entanglement of signals within the class of signals with given TMs.

As the M given signals, signals with the following types of modulation were used: FM2, FM4, QAM16, and signals from the $(M+1)$-th class – signals PM2, AM2, NON. The choice of threshold values in decision rule (4–6) was carried out from the condition of ensuring a given probability of recognition of the TMs $\hat{P}_{cr}$. The values λ_i determine the sizes of the own areas of the given signals in space (A_c, A_s) and accordingly affect not only $P_{(M+1/M)}$ (the probability of "skipping"), but also $P_{(M/M+1)}$ (the probability of "false alarm"). Fig. 2 shows a diagram of the exchange of quality indicators $P_{(M/M+1)}$ and $P_{(M+1/M)}$ obtained at N = 1024 and at a signal-to-noise ratio of 9.54dB.

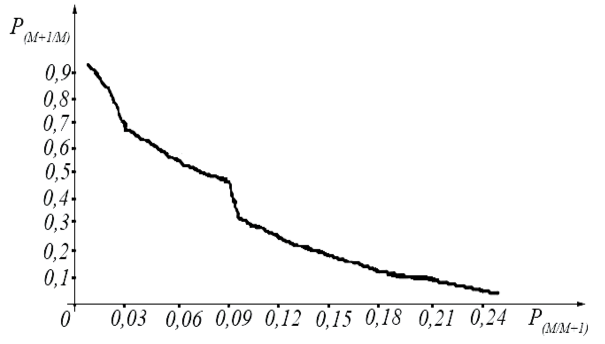

Figure 2 – Diagram of the exchange of indicators of the quality of recognition of given types of signal modulation

From the obtained dependence it follows, that it is impossible to reduce simultaneously both error probabilities. By lowering the threshold values λ_i, the own areas of the given signals are narrowed and the probability of "false alarm" decreases, but at the same time, the probability of "skipping" the given signals increases.

The dependence of the recognition quality of the TMs signals on the duration of their observation N is of particular interest. This dependence is important, because the parameter N, unlike s/n ratio, can be controlled to provide the required quality of recognition of the TMs. Therefore, the dependences of the probability of recognition errors on the length of the implementation of the signals N were investigated. In studies, for each value $N = 8, 16, 32, 64, 128, 256, 512, 1024,$ threshold values λ_i were selected based on the conditions for ensuring the required probability $P_{(M+1/M)} = 0.05$. The obtained dependences are shown in Fig. 3. It can be seen that at $N < 64$, the quality of recognition deteriorates significantly, and at $N > 256$ an acceptable quality of recognition of TMs is provided.

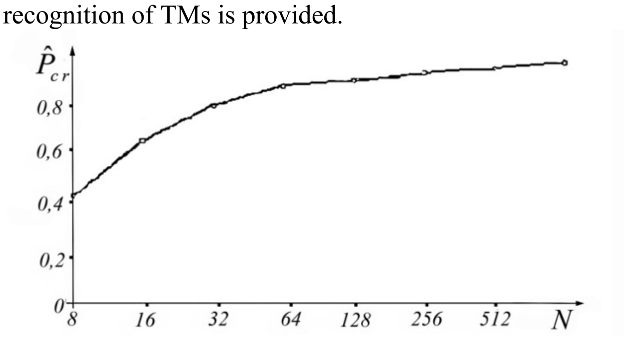

Figure 3 – Dependence of the probability of correct recognition $\hat{P}_{cr}$ of TMs on the length of signal implementations

6 DISCUSSION

From the obtained research results it follows that the considered decision rule for recognizing TMs (2) provides an average probability of correct recognition for all TMs of at least 0.9 with a probability of "false alarm" of not more than 0.02. This corresponds to the real requirements for the quality of recognition of TM signals with automated RM.

The results of the study illustrate the distinctive feature of the proposed method for recognizing given types of modulation in the presence of unknown types of modulation in comparison with traditional methods for recognizing types of signal modulation. In traditional methods of recognizing the types of signal modulation, all unknown types of modulation signals will mistakenly refer to one of the given types of signal modulation. The proposed method for recognizing the given types of modulation uses a two-stage decision-making procedure. In this case, due to the randomness of the observed signals, insignificant probabilities of error in assigning the given types of signal modulation to the class of unknown types of signal modulation $P_{(M+1/M)}$ and vice versa of unknown types of signal modulation to the given types of signal modulation $P_{(M/M+1)}$ are possible. The necessary probability of correct recognition of the type of modulation can be achieved by choosing the appropriate duration of the observed signals N.

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CONCLUSIONS

The solution of the problem of recognition of specified types modulation of signals under conditions of increased a priori uncertainty is considered,

The scientific novelty. New recognition method based on the description of signals by probabilistic model in the form of a mixture of distributions are given.

The practical significance. The obtained values of the quality indicators recognition are acceptable for the practice of radio monitoring.

Prospects for further research. The considered recognition method may be using to solve practical problems of automated radio monitoring.

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МЕТОД РОЗПІЗНАВАННЯ ЗАДАНИХ ТИПІВ МОДУЛЯЦІЇ СИГНАЛІВ, ОСНОВАНИЙ НА ЙМОВІРНІСТНІЙ МОДЕЛІ У ВИДІ СУМІШІ РОЗПОДІЛІВ

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АНОТАЦІЯ

Актуальність. У статті розглянуті особливості вирішення нетрадиційної задачі розпізнавання заданих типів модуляції сигналів в автоматизованому радіомоніторингу. Практичні особливості такої задачі визначають підвищену апріорну невизначеність, яка полягає у відсутності апріорних відомостей про щільності ймовірностей розподілу заданих сигналів і наявності невідомих сигналів.

Мета. Запропоновано вирішення задачі з використанням нетрадиційного методу розпізнавання статистично заданих випадкових сигналів при наявності невідомих сигналів. У цьому методі припускається, що для заданих сигналів мається класифікована навчальна вибірка реалізацій, по якій оцінюються невідомі параметри їх розподілу, а також деякі порогові значення, що визначають ймовірності правильного розпізнавання заданих типів модуляції сигналів при наявності невідомих сигналів.

Метод. Обговорюється загальне вирішення задачі розпізнавання заданих сигналів у присутності невідомих сигналів та приводиться метод розпізнавання заданих типів модуляції, оснований на описі сигналів ймовірнісною моделлю у виді суміші розподілів. Метод базується на описуванні сигналів ймовірнісною моделлю у виді суміші розподілів і побудові замкнутої області для заданих сигналів у ймовірнісному просторі сигналів.

Результати. Проведені дослідження задачі розпізнавання заданих типів модуляції сигналів шляхом статистичних випробовувань на вибірках відповідних сигналів, характерних для автоматизованого радіомоніторингу засобів зв’язку. При цьому вирішувальне правило розпізнавання заданих типів модуляції сигналів програмно реалізовано на ЕОМ. У результаті проведених статистичних випробувань на контрольних вибірках сигналів отримані оцінки ймовірностей правильного розпізнавання заданих типів модуляції сигналів при наявності невідомих сигналів.

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Висновки. Отримані прийнятні для практики радіомоніторингу значення показників якості розпізнавання типів модуляції сигналів. Досліджені залежності показників якості від деяких умов і параметрів розпізнавання У результаті проведених досліджень отримано практичні рекомендації по використанню запропонованого методу розпізнавання заданих типів модуляції сигналів у системах автоматизованого радіомоніторингу.

КЛЮЧОВІ СЛОВА: автоматизований радіомоніторинг, радіовипромінювання, сигнал, тип модуляції, ймовірнісна модель, метод розпізнавання, статистичні випробовування, ймовірність правильного розпізнавання.

УДК 621.391

МЕТОД РАСПОЗНАВАНИЯ ЗАДАННЫХ ТИПОВ МОДУЛЯЦИИ СИГНАЛОВ, ОСНОВАННЫЙ НА ВЕРОЯТНОСТНОЙ МОДЕЛИ В ВИДЕ СМЕСИ РАСПРЕДЕЛЕНИЙ

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АННОТАЦИЯ

Актуальность. В статье рассмотрены особенности решения нетрадиционной задачи распознавания заданных типов модуляции сигналов в автоматизированном радиомониторинге. Практические особенности этой задачи определяют повышенную априорную неопределенность, которая заключается в отсутствии априорных сведений о плотностях распределения заданных сигналов и наличии неизвестных сигналов.

Цель. Предложено решение задачи с использованием нетрадиционного метода распознавания статистически заданных случайных сигналов при наличии класса неизвестных сигналов. В этом методе полагается, что для заданных сигналов имеется классифицированная обучающая выборка реализаций, по которой оцениваются неизвестные параметры их распределений, а также некоторые пороговые значения, определяющие вероятности правильного распознавания заданных видов модуляции сигналов при наличии неизвестных сигналов.

Метод. Обсуждается общее решение задачи распознавания заданных сигналов в присутствии неизвестных сигналов и приводится метод распознавания заданных типов модуляции. Метод основан на описании сигналов вероятностной моделью в виде смеси распределений и построении замкнутой области для заданных сигналов в вероятностном пространстве сигналов.

Результаты. Проведены исследования задачи распознавания заданных типов модуляции сигналов путем статистических испытаний на выборках соответствующих сигналов, характерных для автоматизированного радиомониторинга средств связи. При этом решающее правило распознавания заданных типов модуляции сигналов программно реализовано на ЭВМ. В результате проведенных статистических испытаний на контрольных выборках сигналов получены оценки вероятностей правильного распознавания заданных типов модуляции сигналов при наличии неизвестных сигналов.

Выводы. Получены приемлемые для практики радиомониторинга значения показателей качества распознавания типов модуляции сигналов. Исследованы зависимости показателей качества от некоторых условий и параметров распознавания. В результате проведенных исследований получены практические рекомендации по использованию предложенного метода распознавания заданных типов модуляции сигналов в системах автоматизированного радиомониторинга.

КЛЮЧЕВЫЕ СЛОВА: автоматизированный радиомониторинг, радиоизлучение, сигнал, тип модуляции, вероятностная модель, метод распознавания, статистические испытания, вероятность правильного распознавания.

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