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РАДИОЭЛЕКТРОНИКА И ТЕЛЕКОММУНИКАЦИИ

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SELECTION AND RECOGNITION OF THE SPECIFIED RADIO EMISSIONS BASED ON THE AUTOREGRESSION SIGNAL MODEL

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ABSTRACT

Context. A solution to the relevance problem of selecting and recognizing specified radio emissions in the presence of unknown radio emissions in automated radio monitoring is considered. It is proposed to solve the problem in an unconventional method for the recognition of statistically specified random signals in the presence of a class of unknown signals.

Objective. The goal of the work is investigation of the possibility of using random signal recognition methods in conditions of increased a priori uncertainty to solve the problem. The features of the signal recognition method are discussed, as well as the results of a study of the recognition quality indicators of given radio emissions, which are obtained by statistical modeling on samples of the corresponding signals.

Method. The recognition method is based on the description of signals by a probabilistic model in the form of Gaussian autoregressive processes. It is proposed to use the new decision rule for the selection and recognition of statistically specified signals in the presence of unknown signals class. The proposed method of signal selection and recognition can be implemented in a recognition system that operates in training and recognition modes. In the training mode, unknown parameters of the decision rule are evaluated by classified samples of the given signals.

Results. Research conducted by statistical tests on samples of the corresponding signals characteristic of automated radio monitoring of radio communications equipment. Practical results of studies of the problem of selection and recognition of specified radio emissions are presented. 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 investigated.

Conclusions. Undertaken studies showed possibility of decision of problem by application of an unconventional method of selection and recognition of specified random signals. The practical significance lies in obtaining recommendations on the construction of systems for the recognition of radio emissions for specialists in the design of automated radio monitoring complexes. Such signal recognition systems are implemented by computer technology and is adaptive. The structure and parameters of the systems are set according to the samples of signals that are obtained for the corresponding given radio emissions.

KEYWORDS: automated radio monitoring, radio emission, autoregressive model, selection, recognition, decisive rule, statistical tests, recognition system.

ABBREVIATIONS

RM is a radio monitoring;

RE is a radio emission;

AR is a autoregressive.

NOMENCLATURE

M is a number of classes of recognizable signals;

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

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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;

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

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

n_i is a volume of the training samples;

λ is a threshold value;

Λ_l is a thresholds values;

$K_l(\vec{x})$ is a normalized prediction error in the AR model;

p_l is a order of the AR model for the l-th given signal;

a_j^l is a autoregression coefficients in the AR model for the l-th given signal;

$\hat{P}_{err.av.}$ is a probability of erroneous signal recognition;

$\hat{P}_{un/g}$ is a probability of erroneous decisions about the action of unknown signals when presenting the given signals;

$\hat{P}_{g/un}$ is a probabilities of erroneous decisions about the action of the M given signals under the condition of presenting unknown signals.

INTRODUCTION

Conducting automated radio monitoring, a panoramic overview of the frequency ranges is carried out and the problems of detection and recognition of radio emissions are solved by the corresponding signals [1–3]. After the detection of radiation sources in the frequency channels, there is a need to solve the problems of recognizing given radiation sources previously represented by their training samples of signals that are used to overcome a priori uncertainty. For these purposes, various methods of recognition of observations can be used, including the recognition and classification of types of signal modulation [2–9]. However, along with the given REs, many other unknown REs, not represented by training samples of signals, come to recognition, which characterizes the increased a priori uncertainty. Therefore, it becomes necessary to solve relevance problems of selection and recognition of specified REs under conditions of increased a priori uncertainty. Under these conditions, classical methods for pattern recognition [10, 11] cannot be used.

It should be noted one more feature of solving recognition problems in automated RM. Due to the effects of noise and many other uncontrolled factors, the signals in the frequency channels are random in nature. Therefore, statistical methods of pattern recognition should be used for recognition [11–13]. Therefore, for the mathematical description of the observed signals probabilistic models can be used [14]. The selected model should be adequate to the solved problem of REs recognition. When solving the problems of signal recognition based on the selected probabilistic model, the presence of unknown signals should be taken into account. In [15, 16], the problems of signal detection and recognition were solved on the basis of a probabilistic model in the form of orthogonal signal decompositions.

The object of study is the process of solving recognition problems in automated RM by using random signal recognition methods in conditions of increased a priori uncertainty.

The subject of study is the sampling methods for selection and recognition of given signals in the presence of unknown signals, based on the autoregression signal model.

The purpose of this work is to investigate of the recognizing specified REs on samples of the corresponding signals in automated RM. This article discusses the features of solving the problem of selection and recognition of given signals in the presence of unknown signals for the case when a probabilistic model of the observed signals in the form of autoregressive processes is used to describe the signals [17–19]. Based on this mathematical model of signals, the decisive rule for the selection and recognition of given signals is synthesized. Investigations of the recognizing task specified REs by means of statistical tests on samples of the corresponding signals characteristic of an automated RM of communication facilities have been performed. Some results of REs recognition are presented, which confirm the possibility of solving the set recognition problem with quality indicators acceptable for the practice of automated RM.

1 PROBLEM STATEMENT

In classical recognition problems, it is usually assumed that the number of testable hypotheses M is equal to the number of classes of recognizable signals defined in a probabilistic sense. However, in real problems of automated RM, situations arise when the observed signal may not belong to the given classes of signals and should be assigned to the $(M+1)$-th class of unknown signals not specified in the probabilistic sense. Therefore, we consider the features of a formalized formulation for such a nonclassical signal recognition problem. We will assume that the recognized signals are represented by finite-dimensional random vectors of some observations $\vec{x}$, according to the implementation of which decisions are made. The hypotheses $(M+1)$ that can be made with respect to the observed signals are set: H^i, $i=\overline{1,M}$ – for given signals, H^{M+1} – for unknown signals combined in the $(M+1)$-*i*th class. The probability densities of given signals $W(\vec{x}/\vec{\alpha}^i)$, $i=\overline{1,M}$ are specified up to random vector parameters α^i, $i=\overline{1,M}$, and for the $(M+1)$-*i*th class the probability density is unknown. A priori probabilities of hypotheses are also given $P(H^i)=P_i$, and

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$\sum_{i=1}^{M+1} P_i = 1$. It is also believed, that training samples for M signals $\{\vec{x}_r^i, r=\overline{1,n_i}; i=\overline{1,M}\}$ are given, and a training sample for the $(M+1)$-*n*th signal is missing.

2 REVIEW OF THE LITERATURE

Features of signal processing tasks during automated radio monitoring are considered in [1–3]. In particular, the importance of solving the problems of recognizing radio emissions from the signals representing them is noted. In [4–9] the features of solving the problem of automatic classification of signal modulations during radio monitoring are considered. In [4,7], a method for automatic recognition of modulation types for radar and communication signals is presented, which is based on a comparison of metrics in the signal space. In [8], methods for automatic recognition of types of signal modulation based on the use of wavelet transforms and neural networks are proposed.

The tasks of recognizing signals corresponding to given radio emissions 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 [10–13]. A priori uncertainty is overcome using classified training samples of recognized signals.

For the mathematical description of the observed signals probabilistic models can be used [14]. The selected model should be adequate to the solved problem of REs recognition.

When solving the problems of signal recognition based on the selected probabilistic model, the presence of unknown signals should be taken into account. In [15, 16], spectral methods for solving the problems of signal detection and recognition are considered, which are based on a probabilistic model in the form of orthogonal signal decompositions.

In classical recognition methods, which were considered in [10–13], it is assumed that during recognition the number of tested hypotheses is equal to the number of recognized signal classes. However, during radio monitoring for recognition, in addition to the specified REs, there are also a lot of unknown REs not represented by training samples of signals. Therefore, for the recognition of REs classical methods of signal recognition can not be used. This determines the relevance of using non-traditional methods of signal recognition in the presence of a class of unknown signals, which were proposed in [15–17]. These methods are based on the determination of some own regions in the signal space using training samples of given signals. Moreover, the features of signal recognition methods are determined by probability models selected for signal description.

In some cases, an autoregressive model is convenient for solving signal recognition problems. In [18] an appropriate signal recognition method based on the autoregressive model was proposed. However, these methods of signal recognition based on the autoregressive model do not take into account the presence of a class of unknown signals. In [19], the use of such methods of selection and recognition of statistically defined signals in training systems for solving practical problems of radar, radio monitoring, medical diagnostics, and speaker identification was considered.

Therefore, it is of interest to study the method of selection and recognition of given random signals in the presence of a class of unknown signals to solve the problem of recognizing given radio emissions in automated radio monitoring.

3 MATERIALS AND METHODS

According to the formulated problem, it is necessary to solve the non-traditional problem of selection and recognition of given signals in the presence of unknown signals. To do this, use the following decision rule [11]:

– if the system of inequalities holds

$$H^i : \max_{l=1,M} \{ P_l W(\vec{x} / \vec{\alpha}^i) \} \geq \lambda, \tag{1a}$$

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

then the hypothesis about the action of the i-nth given signal is accepted;

– if inequalities hold

$$H^{M+1} : \max_{i=1,M} \{ P_l W(\vec{x} / H^l) \} < \lambda, \tag{1c}$$

then the hypothesis about the action of unknown signals is accepted.

In decision rule (1) unknown parameters of signal distribution densities $\vec{\alpha}$ are estimated from training samples of observations for M given signals, and the threshold value λ is determined from the condition of ensuring a given probability of correct recognition of given signals.

The solution to such an unconventional recognition problem involves the selection and subsequent recognition of given signals and assigning unknown signals to a separate class of signals, information about which is insufficient for their recognition. The principle of solving this recognition is based on the construction in the signal space of some closed own regions for given signals using training samples of given signals. The size and shape of these own regions depends on the type of distribution densities of the given signals and threshold values in the decision rule (1). When observations fall into one of their own regions, a decision is made on the action of the corresponding given signal. Otherwise, a decision is made to observe an unknown signal. The form of the distribution densities of the given signals largely depends on the probabilistic model chosen for the description of the signals.

With an automated RM of communication media, the corresponding radiation sources are represented by signals

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with energy spectra, which are characterized by the presence of pronounced extremes. It is rational to use an autoregressive model to describe such signals. If the signals are described by a probabilistic model in the form of Gaussian autoregressive processes, the decisive recognition rule (1) is specified in the following form [11]:

– if the system of inequalities holds

$$H^l : K_l(\vec{x}) < \Lambda_l, \quad l = \overline{1, M}\ , \tag{2a}$$

$$K_l(\vec{x}) - K_i(\vec{x}) + \ln \frac{(2\pi\sigma_i)^{p_i - L}}{(2\pi\sigma_k)^{p_k - L}} \geq \ln \frac{P_l}{P_i}, \tag{2b}$$

then the hypothesis about the action of the i-nth given signal is accepted;

– if inequalities hold

$$H^{M+1} : K_l(\vec{x}) > \Lambda_l, \quad l = \overline{1, M}, \tag{2c}$$

then the hypothesis about the action of an unknown signal is accepted.

Here $K_l(\vec{x}) = \frac{1}{2\sigma_l^2} \sum_{k=p+1}^{L} \left[x_k - \mu_l - \sum_{j=1}^{p_l} a_j^l (x_{k-j} - \mu_l) \right]^2$ is the normalized prediction error in the AR model; p_l, a_j^l – the order and autoregression coefficients for the l-th given signal; $\Lambda_l = \ln \frac{(2\pi)^{\frac{L}{2}} \sigma_l^{L - p_l} \lambda_l}{P_l}$ – some threshold values selected from the conditions for ensuring the probabilities of correct recognition of M given signals.

In decision rule (2), it is assumed that for unknown parameters of AR models for M given signals, their estimates are calculated using classified training samples of given signals. In particular, the AR coefficients are found from the Yule-Walker equation, which uses correlation matrix estimates obtained from training samples of given signals.

The proposed method of signal selection and recognition can be used in a signal recognition system, which is quite easily implemented by computer technology and is adaptive. The structure and parameters of the recognition system are adjusted according to the classified samples of signals obtained for the corresponding given radio emissions.

4 EXPERIMENTS

The study of the problem of selection and recognition of given signals was carried out by statistical testing of the decision rule (2) on samples of signals with different types and modulation parameters characteristic of the problems of radio monitoring of radio communications equipment. The energy spectra of these signals are shown in Fig. 1.

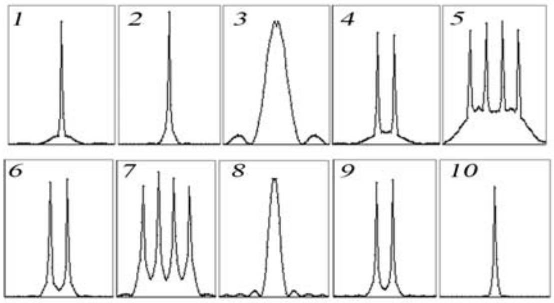

Figure 1 – Energetically spectra of communication signals with various types and modulation parameters

A study was made of the quality indicators of the solution to the problem of selection and recognition of given signals in the presence of unknown signals. Signals (1–5) were used as given signals, the remaining signals (6–10) were considered as unknown signals. Training samples of given signals were used to evaluate the unknown parameters of the decision rule (2). Control samples of given and unknown signals were used in statistical tests. The volumes of training and control samples were set for 1000 realizations for each signal.

5 RESULTS

As a result of studies, the dependence of the average probability of erroneous recognition of given signals $\hat{P}_{err.av.}$ on the selected order of the AR model p was obtained (Fig. 2).

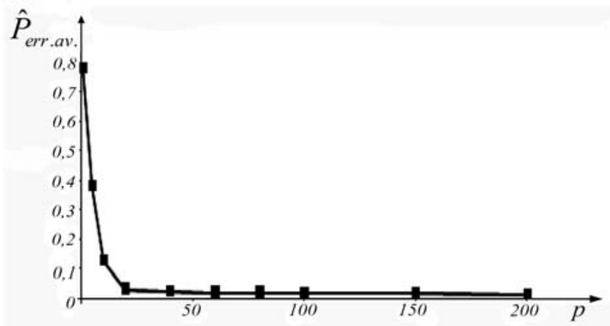

Figure 2 – The dependence of the average probability of erroneous signal recognition $\hat{P}_{err.av.}$ on the order of the AR model p

It was found that for the order of the AR model p = 20, a rather low probability of erroneous signal recognition $\hat{P}_{err.av.}$ is achieved, which indicates the adequacy of the model selected for describing the signals of the AR.

Estimates are also obtained of such indicators of recognition quality: $\hat{P}_{un/g}$ – the probability of erroneous decisions about the action of unknown signals when resenting the given signals and $\hat{P}_{g/un}$ – the probabilities of erroneous decisions about the action of the M given signals under the condition of presenting unknown signals. The diagrams of the exchange of recognition quality indicators $\hat{P}_{un/g}$ and $\hat{P}_{g/un}$ for different

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dimensions of realizations of the observed signals $L = 256$ and $L = 512$ are shown in Fig. 3.

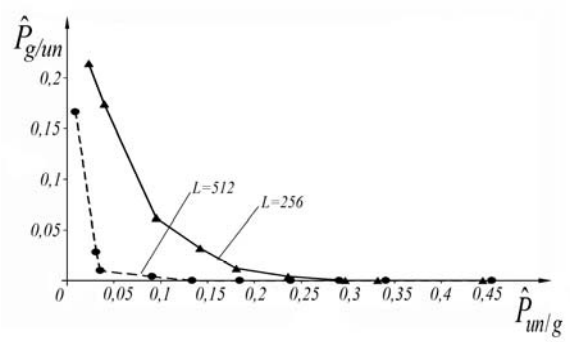

Figure 3 – Diagram of the exchange of quality indicators $\hat{P}_{un/g}$ and $\hat{P}_{g/un}$ for the recognition of given signals in the presence of unknown signals

6 DISCUSSION

As follows from the results of the studies, the proposed method of selection and recognition of given signals provides a sufficiently high quality of signal recognition. This confirms the adequacy of the probability model chosen to describe the signals in the form of Gaussian autoregressive processes with a low order autoregressive model.

It is seen that an improvement in the value of one indicator of the quality of signal recognition $\hat{P}_{un/g}$ can be achieved by deteriorating the value of another indicator of the quality of recognition $\hat{P}_{g/un}$. Such an interchange between the values of these indicators of signal recognition quality can be carried out by changing the threshold values Λ_l in the decision rule (2).

It is also seen that an improvement in the quality of signal recognition can be achieved both by increasing the order of the AR model, and by increasing the observation time (dimension L of the observed vectors $\vec{x}$).

In general, the obtained research results confirm the possibility of ensuring the required quality of recognition of the given REs, acceptable for the practice of automated RM.

CONCLUSIONS

The solution of the relevance problem of selection and recognition of specified radio emissions under conditions of increased a priori uncertainty is considered, when along with the radio emissions specified by their training samples of signals, unknown radio emissions are presented.

The scientific novelty. A new decision rule is proposed for the selection and recognition of given signals in the presence of unknown signals based on the description of the signals by a mathematical model in the form of Gaussian autoregressive processes.

The practical significance. A study of the problem of selection and recognition of specified REs was conducted by statistical tests of the proposed decision rule on samples of corresponding signals characteristic of communications radio monitoring.

Prospects for further research. Estimates of the quality indicators of recognition of specified radio emissions are obtained, which make it possible to use the considered method of selection and recognition of specified radio emissions in solving practical problems of utomated radio monitoring.

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СЕЛЕКЦІЯ І РОЗПІЗНАВАННЯ ЗАДАНИХ РАДІОВИПРОМІНЮВАНЬ В ЗАДАЧАХ АВТОМАТИЗОВАНОГО РАДІОМОНІТОРИНГУ

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АНОТАЦІЯ

Актуальність. Вирішено актуальну проблему вибору і розпізнавання заданих радіовипромінювань при наявності невідомих радіовипромінювань в автоматизованому радіомоніторингу. Поставлену проблему запропоновано вирішити нетрадиційним методом роспізнавання статистично заданих випадкових сигналів при наявності класу невідомих сигналів.

Мета. Метою даної роботи є дослідження можливості застосування методів розпізнавання випадкових сигналів в умовах підвищеної невизначеності. Обговорюються особливості методу розпізнавання сигналів, а також результати дослідження показників якості розпізнавання заданих радіовипромінювань, що отримані шляхом статистичного моделювання на вибірках відповідних сигналів.

Метод. Метод розпізнавання заснований на описі сигналів ймовірнісною моделлю у вигляді гауссовських авторегресійних процесів. Використано нове правило прийняття рішення щодо селекції і розпізнавання статистично заданих сигналів при наявності класу невідомих сигналів. Запропонований метод селекції та розпізнавання сигналів може бути реалізований у системі розпізнавання, що працює в режимах навчання та розпізнавання. У режимі навчання невідомі параметри правила прийняття рішень оцінюються по класифікованим вибіркам заданих сигналів.

Результати. Дослідження проведені шляхом статистичних випробувань на вибірках відповідних сигналів, характерних для автоматизованого радімоніторінгу засобів радіозв'язку. Представлені практичні результати селекції та распознавания заданних радіовипромінювань. Отримані прийнятні для практики радіомоніторингу значення показників якості розпізнавання радіовипромінюваь. Досліджені залежності показників якості розпізнавання від деяких умов і параметрів розпізнавання.

Висновки. Проведені дослідження показали можливість використання нетрадиційного методу селекції і розпізнавання заданих випадкових сигналів для вирішення поставленної проблеми. Практична значимість полягає в отриманні рекомендацій з побудови систем розпізнавання радіовипромінювань для фахівців у галузі розробки автоматизованих комплексів радіомоніторингу. Такі системи розпізнавання сигналів реалізуються засобами обчислювальної техніки та

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являются адаптивними. Структура і параметри систем розпізнавання устанавлюються по навчальним вибіркам сигналів, які отримані для заданих радіовипромінювань.

КЛЮЧОВІ СЛОВА: автоматизований радіомоніторинг, радіовипромінювання, сигнал, авторегресійна модель, селекція, розпізнавання, правило прийняття рішення, статистичні випробування, система розпізнавання.

УДК 621.391

СЕЛЕКЦИЯ И РАСПОЗНАВАНИЕ ЗАДАННЫХ РАДИОИЗЛУЧЕНИЙ В ЗАДАЧАХ АВТОМАТИЗИРОВАННОГО РАДИОМОНИТОРИНГА

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АННОТАЦИЯ

Актуальность. Решена актуальная проблема выбора и распознавания заданных радиоизлучений при наличии неизвестных радиоизлучений в автоматизированном радиомониторинге. Поставленную задачу предложено решать нетрадиционным методом распознавания статистически заданных случайных сигналов при наличии класса неизвестных сигналов.

Цель. Целью данной работы является исследование возможности применения метода распознавания заданных случайных сигналов в условиях повышенной неопределенности. Обсуждаются особенности метода распознавания сигналов, а также результаты исследования показателей качества распознавания заданных радиоизлучений, которые получены путем статистического моделирования на выборках соответствующих сигналов.

Метод. Метод распознавания основан на описании сигналов вероятностной моделью в виде гауссовских авторегрессионных процессов. Использовано новое решающее правило селекции и распознавания статистически заданных сигналов при наличии класса неизвестных сигналов. Предлагаемый метод селекции и распознавания сигналов может быть реализован в системе распознавания, которая работает в режимах обучения и распознавания. В режиме обучения неизвестные параметры решающего правила оцениваются по классифицированным выборкам заданных сигналов.

Результаты. Исследования проведены путем статистических испытаний на образцах соответствующих сигналов, характерных для автоматизированного радиомониторинга средств радиосвязи. Представлены практические результаты селекции и распознавания заданных радиоизлучений. Получены приемлемые для практики радиомониторинга значения показателей качества распознавания радиоизлучений. Исследованы зависимости показателей качества от некоторых условий и параметров распознавания.

Выводы. Проведенные исследования показали возможность использования нетрадиционного метода селекции и распознавания заданных случайных сигналов для решения поставленной проблемы. Практическая значимость заключается в получении рекомендаций по построению систем распознавания радиоизлучений для специалистов в области разработки автоматизированных комплексов радиомониторинга. Такие системы распознавания сигналов реализуются средствами вычислительной техники и является адаптивными. Структура и параметры систем устанавливаются по обучающим выборкам сигналов, которые получены для заданных радиоизлучений.

КЛЮЧЕВЫЕ СЛОВА: автоматизированный радиомониторинг, радиоизлучение, сигнал, авторегрессионная модель, селекция, распознавание, решающее правило, статистические испытания, система распознавания.

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