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SOURCE IDENTIFICATION METHODOLOGY IN RADIO MONITORING OBJECTS USING MULTI-MEANING

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Background. With the constant development of radio-electronic equipment and telecommunication technologies and the appearance of new technical means of various purposes, including dual meaning, which already have and operate with new “non-traditional” information features. The specified circumstances require the improvement of their radio monitoring and countermeasure systems, from the point of view of the development of highly effective intelligent systems that ensure the collection, processing, accumulation and use of the received monitoring information for decision-making on a real-time scale.

Objective. Increasing the effectiveness of radio monitoring of radio radiation sources is carried out by decomposing their informational features into static and dynamic ones with further formalization of the observation and decision-making process.

Methods. The decision on whether the source of radio radiation belongs to one or another class is made on the basis of a preliminary calculation of information feature estimates for all possible sets of features and the use of multi-valued logic functions to make a decision. The preliminary calculation makes it possible to increase the speed of the algorithm and make a decision about whether the object of recognition belongs to one or another class by calculating the value of only one function, and recalculating the estimates of static and dynamic information features only when the descriptions of classes of radio radiation sources are changed.

Results. The proposed technique makes it possible to significantly expand the classes of classes of sources and objects of radio monitoring and will ensure an increase in the speed and reliability and efficiency of the recognition process as a whole.

Conclusions. Deciding whether a source of radio radiation belongs to one or another class through the use of multi-valued logic functions allows increasing the efficiency of the radio monitoring system and significantly expand the class of monitoring sources.

Keywords: *radio monitoring; information feature; recognition; classification; evaluation; algorithm; functions of multi-valued logic.*

Introduction

The discussion of recent years regarding the deepening of trends in the reduction of the efficiency of monitoring structures of technical types and means of observation in general, and in particular the monitoring of sources and objects of radio radiation (SORr), has currently led to a known problematic situation in this field [1-3]. It is characterized by the fact that, on the one hand, monitoring specialists and authors of numerous theoretical publications in this subject area offer new approaches to the processes of information collection, accumulation and processing, which are based on the methodologies of a systematic approach and comprehensive digitalization. On the other hand, the proposed approaches and methods have a general theoretical, recommended nature and are oriented towards fairly old and simple situations where the issues of information support are considered before all special forces (the fight against international terrorism, maritime and computer piracy, banditry, illegal arms trade, drug business, illegal emigration, etc.).

At the same time, in the conditions of war and fighting for the independence of Ukraine, the issues of radio monitoring and decision-making receive special attention. Also, the rapid development of modern telecommunications and computer technologies, computing equipment, radio electronics, etc. leads to the appearance of new technical means of various purposes, including dual meaning, which already have and operate with new "non-traditional" information features. The specified circumstances require the improvement and development of RM systems and countermeasures, first of all from the standpoint and methodology of highly effective intelligent systems that ensure the collection, processing, accumulation and use of the received monitoring information for decision-making on a real-time scale. That is, the RM system as a whole should be considered as an open automated intelligent system with all inherent attributes, and which should solve one of the main tasks, which is to recognize and classify SORr and determine their phase (operational) state and the degree of possible threats (danger) [1-3].

As the analysis of known literary sources shows, the tasks of classification and recognition of SORr can most effectively be solved on the basis of the provisions of the structural-systemic and signature methods (SCM) of RM management [3], where classification is understood as the division of the entire set of SORr into non-intersecting classes, and recognition - assigning the object of observation to one or another class. The essence of the process under consideration is the comparison of a priori knowledge (presupposes the developed information models) about the SORr and a posteriori data coming from the RM means, and making a decision on the recognition of the object of observation. A priori knowledge and a posteriori data are formed (both in advance and in the dynamics of the RM management process) on the basis of sets of information features (IF) or information signatures (IS).

In SCM, signatures are considered as sets of statistical information features at a fixed moment of time t, and their formalization and processing algorithms are developed mainly on the basis of correlation theory [3,4]. At the same time, the logical methods of formalization and processing in this subject area were practically not reflected in solving the specified problems, and were considered only from general positions using the provisions of binary logic (Boolean algebra).

The formalization of dynamic signatures from statistical-correlation positions is quite complex and can lead to the appearance of recognition errors of both the first and second kind and their accumulation. The description of signatures with the help of binary logic functions has a number of essential disadvantages, the main of which is the limitation and the possibility of providing IF only with values 0 and 1.With the constant development of radio electronic equipment and telecommunication technologies and the emergence of new types of SORr, characterized by a whole series of specific IO and IS, the necessity of their decomposition into static and dynamic with further formalization and processing by correlational and logical methods became obvious. At the same time, among logical methods, preference should be given to well-known methods of multi-valued logic (k-logic), on the basis of which relatively simple methods and algorithms for recognition of DRVp can be developed quite effectively.

In [5], the authors limited themselves to a description of the general approach and basic procedures for calculating estimates of static and dynamic IFs in the recognition and classification of SORr and the structural diagram of their automatic classification system and the recognition and decision-making algorithm. Therefore, based on the above, the purpose and main content of the article is a description of the method of recognizing sources and objects of radio radiation during their monitoring using functions of multi-valued logic (k-logic) and digitalization of the observation process.

Main part.

It is known that the function of multi-valued (k-valued) logic is the function $f(x_1,x_2,...x_n)$, where the arguments take values from the set {0,1,2,...,k-1} and which on any set of argument values takes values from the same set {0,1,2,…,k-1}. That is, the functions of multi-valued logic, in comparison with two-valued ones, describe processes where the arguments and the function can take values from the finite set {0,1,2,…,k-1}, and not {0,1}, as for Boolean functions . Any positive integer greater than 1 can be chosen as the number k. Functions of multi-valued logic are specified both with the help of tables that include all possible sets of argument values and their corresponding function values (similar to the truth tables of a Boolean function), and in the form of a polynomial, built according to the values of the specified table.

As stated in [5], the initial data for solving recognition tasks are:

a priori known areas of permissible values of each IF;

information models of SORr classes in the form of aggregates of values of static and dynamic features;

the value of the weight coefficients of static and dynamic features characterizing the in formativeness of each IO when making a decision in favour of a given class;

a similar description of the object of recognition through the value and .

If the signatures of l classes are known a priori, which are described in the form of a set of values of s static and n dynamic IOs at time points from 0 to t, then the initial data for recognition is provided in the form shown in Fig. 1.

For the convenience of providing vectors , $\overline{Y}_{sfi}$, $\overline{R}_{sfi}$, $\overline{Y}_{dfi}$ та $\overline{R}_{dfi}$, and $i=\overline{1,l}$ information models of SORr classes are reduced to the following matrices: Y_{sf}, R_{sf}, dimensions ; $n \times l$ - dimensions and $n \times l \times t$ - dimensions.

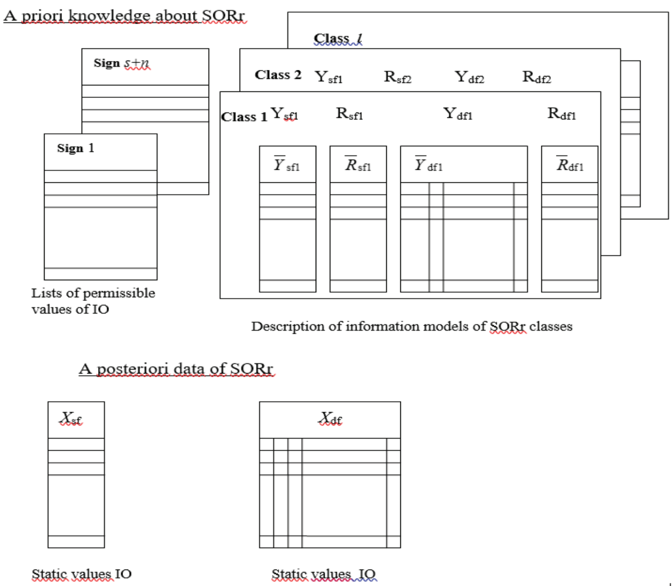

Fig. 1. Presentation of raw data for recognition

Recognition and classification of SORr with the help of the algorithm proposed in [5] requires calculation of estimates of static and dynamic IOs for each class of recognition objects, combining estimates of static and dynamic features into a total estimate and calculation of the probabilities with which the object of recognition can be assigned to each of the reference classes.

The decision on recognition is made on the basis of the analysis of the obtained probabilities. At the same time, the calculation of estimates of static and dynamic IO in favour of the i-th class is carried out according to the formulas:

$$f_{\mathrm{sf}\,i} = \sum_{j=1}^{s} r_{\mathrm{sf}\,ij} \left| (x_{\mathrm{sf}\,j} = y_{\mathrm{sf}\,ij}) \right. ; \quad (1)$$

$$f_{\mathrm{df}\,i} = \sum_{j=1}^{n} r_{\mathrm{df}\,ij} \cdot k_{ij} , \quad (2)$$

where: $x_{\mathrm{sf}\,j}$ – the value of the received estimate of the j – th static feature of the recognition object;

$y_{\mathrm{sf}\,ij}$ – value of the j – th static feature of the i - th standard;

$r_{\mathrm{df}\,ij}$ та $r_{\mathrm{sf}\,ij}$ – weighting coefficients characterizing the informativeness of the j – th assessment of the feature when it is taken into account in favour of the i – th standard;

k_{ij} – the coefficient of similarity of the dynamics of changes of the received estimate of the j – th dynamic IO when comparing it with the corresponding feature of the i – th standard.

The similarity coefficients of dynamic IOs are calculated according to the least squares formula:

$$k_{ij} = \frac{1}{\sum_{i=1}^{n} y_i^2{}_{df}(t) - \sum_{j=1}^{m} x_{i\,df}(t) \sum_{i=1}^{n} r_{df\,ij}\, y_{i\,df}(t)} \quad (3)$$

where: m is the number of measurements and obtained estimates for comparison;

$x_{i\;df}$ (t), $y_{i\;df}$(t) – accordingly, obtained estimates and reference values of dynamic IOs at the moment of time t.

The probabilities with which this object of recognition can be assigned to each of the l reference classes is calculated by the expression [5]:

$$p_{\Sigma i} = \frac{p_{\text{sf}i} \cdot p_{\text{df}i}}{\sum_{j=1}^{l} p_{\text{df}j} \cdot p_{\text{df}j}}, \tag{4}$$

where: $p_{\text{sf}i} = \frac{f_{\text{sf}i}}{\sum_{j=1}^{l} f_{\text{sf}j}}$, $p_{\text{df}i} = \frac{f_{\text{df}i}}{\sum_{j=1}^{l} f_{\text{df}j}}$.

This approach requires significant computing power and time costs to ensure real-time processing of information data from monitoring tools.

Calculating scores and deciding whether an object belongs to one or another class can be simplified by pre-calculating scores for all possible sets of features and using multi-valued logic functions to make a decision. Pre-calculation of grades allows replacing in the recognition algorithm [5] the calculation of grades according to formulas (1, 2) by searching for their values in a table calculated and compiled in advance, which makes it possible to increase the speed of the algorithm as a whole. The use of multi-valued logic functions will make it possible to make a decision about whether the object of recognition belongs to one or another class by calculating the value of one function, and recalculating the estimates of static and dynamic IFs can be performed only when the descriptions of SORr classes are changed.

That is, the method of recognizing SORr using functions of multi-valued logic (k-logic) consists of the following procedures:

development of information models and identification of IF;

Decomposition of IF into static and dynamic;

description and provision of IF in the form of raw data;

calculation of evaluation values for static features;

calculation of assessment values for dynamic features;

combining the calculated values of static and dynamic IF estimates;

determining the value of the threshold and making the right decision.

As you can see, one of the tasks in recognition consists in formalizing and taking into account static IFs, and the second is in carrying out similar procedures with dynamic features.

Suppose that the recognition and classification system has l information models of classes of objects, which are described by the values of s static IFs. Since the set of permissible values of each feature is known a priori, the set of k elements {1,2,...,k-1} can be chosen as the alphabet of static IOs, where the numbers from 0 to k-1 reflect the serial number of the feature in its table permissible values. If we take into account that l ≤ k, then the table of values of estimates of static features calculated according to formula (1), or the matrix Fst of dimension l×s of all possible sets of permissible values of IF, will have the form given in Tab. 1.

Table 1

x_0	x_1	…	x_{s-}	$f_{\text{ст}0}$	$f_{\text{ст}1}$	…	$f_{\text{ст}l-}$
0	0	…	0	$f_{\text{ст}00}$	$f_{\text{ст}10}$	…	$f_{\text{ст}l-}$
0	0	…	1	$f_{\text{ст}01}$	$f_{\text{ст}11}$	…	$f_{\text{ст}l-}$
0	0	…	2	$f_{\text{ст}02}$	$f_{\text{ст}12}$	…	$f_{\text{ст}l-}$
…	…	…	...	…	…	…	…
k-	k-	…	k-	$f_{\text{ст}0k-}$	$f_{\text{ст}1k-}$	…	$f_{\text{ст}l-}$

The threshold for making a decision in favour of one or another class is determined by the R_{sf} matrix of IF weighting coefficients (see Fig. 1):

$$p = \min_{i=0}^{l-1} \sum_{j=0}^{s-1} r_{ij} . \tag{5}$$

Based on the values of the Fst matrix coefficients, taking into account the selected decision threshold p, the decision truth function f_r is formed (Table 2).

where:

$$f_{rj} = \begin{cases} 0, \text{if } \ f_{\text{ст}ij} < p \ \forall i \\ i, \text{ if } \ \exists f_{\text{ст}ij} \geq p \end{cases} \qquad (6)$$

Table 2

x_0	x_1	…	$x_{s\text{-}1}$	f_r
0	0	…	0	f_{r0}
0	0	…	1	f_{r1}
0	0	…	2	f_{r2}
…	…	…	...	…
k-1	k-1	…	k-1	$f_{r(k-}$

As a result, a multivalued logic function is obtained (with a logic modulus equal to k), which can also be represented in the form of a polynomial composed according to known algorithms [6].

Let's pay attention to the following: if the number l of information models of SORr classes described in the system exceeds the number k, then the number l is chosen as the logic module.

In general, three situations are possible during recognition by the proposed method:

complete coincidence of the recognition object's IF values with the values of one of the standards;

partial coincidence of the recognition object's IF values with the values of one of the standards;

complete mismatch of the values of the IF of the object of recognition with the values of any of the standards.

If the values of the IF of the observation object completely coincide with the values of one of the standards, it is possible to build a function of multi-valued logic f_r' to make a decision about recognition without calculating scores. The arguments of this function are sets of numbers of IF values of the recognition object, and the function takes the value of the number of the reference model with which an exact match occurred.

The final decision on recognition is made in two stages. At the first stage, the value of the function f_r' is calculated and analysed. If $f_r' \neq 0$, then there is a complete coincidence of the IF values of the observation object with one of the standards, and the decision is made according to the f_r' function. At the second stage, if $f_r' = 0$, the decision is made based on the function f_r, given in Table 2. If both $f_r' = 0$ and $f_r, = 0$, then it is concluded that recognition is impossible with such initial data.

The second part of the task of recognition consists in the formalization and accounting of dynamic IFs. It is solved similarly according to the procedures discussed above. At the same time, the difference is that here it is necessary: to calculate the coefficients of the similarity of the dynamics of the change of features according to the expression (3); normalize the obtained values by the selected value of the logic module (*k or l*); round the normalized values to whole numbers and use these data to build a table of estimates and a truth table, similar to Tables 1 and 2.

Thus, when solving the task of recognizing and classifying SORr using methods of multi-valued logic, it is necessary to decompose IO into static and dynamic components, formalize and describe their values, determine their weighting coefficients, i.e. perform the stage of preparation and provision of initial data. After that, based on expressions (1–6), calculate static and dynamic IF estimates, similarity coefficients, determine the value of the decision threshold and form a truth table or polynomial of multivalued logic.

To explain the essence of the proposed technique at the physical level, let's consider the process of recognition and classification of the PM object on a fairly simple example.

Suppose that three reference models of RM objects y_1, y_2 and y_3, are described in the recognition system, each of which is characterized by the values of three static IFs x_1, x_2 and x_3. Let each of the signs take any value from a fixed set:

$$x_1 \in \{x_1^1, x_1^2, x_1^3\};$$

$$x_2 \in \{x_2^1, x_2^2, x_2^3\};$$

$$x_3 \in \{x_3^1, x_3^2, x_3^3\}.$$

Without breaking commonality, suppose that:

the standard y1 is described by the values:

$x_1 = x_1^1$;

$x_2 = x_2^2$;

$x_3 = x_3^3$;

the standard y2 is described by the values:

$x_1 = x_1^2$;

$x_2 = x_2^2$;

$x_3 = x_3^1$;

the etalon y3 is described by the values:

$x_1 = x_1^1$;

$x_2 = x_2^3$;

$x_3 = x_3^2$.

Thus, the matrix characterizing information models y_1, y_2 and y_3 , will have the form:

$$Y_{\text{ст}} = \begin{pmatrix} 1 & 2 & 1 \\ 2 & 2 & 3 \\ 3 & 1 & 2 \end{pmatrix}, \qquad (7)$$

where the columns contain the numbers of feature values from the corresponding ranges of permissible values.

If the weighting coefficients of IF $r_{\text{ст}ij}$ are significant and create a matrix, for example, of the following form:

$$R_{\text{sf}} = \begin{pmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 2 & 2 & 2 \end{pmatrix}, \qquad (8)$$

then, if the values of the static features x_1, x_2 and x_3 fully coincide with the standards y_1, y_2 and y_3, the values of these estimates $f_{\text{ст}i}$ (with known values of the weighting coefficients $r_{\text{ст}ij}$ in the matrix) will be determined and equal to the following values:

$$f_{\text{ст}1} = \sum_{j=1}^{3} r_{\text{ст}1j} \big| (x_{\text{ст}j} = y_{\text{ст}1j}) = 4;$$

$$f_{\text{ст}2} = \sum_{j=1}^{3} r_{\text{ст}2j} \big| (x_{\text{ст}j} = y_{\text{ст}2j}) = 3; \qquad (9)$$

$$f_{\text{ст}3} = \sum_{j=1}^{3} r_{\text{ст}3j} \big| (x_{\text{ст}j} = y_{\text{ст}3j}) = 3 \cdot$$

The obtained results indicate that the threshold value for making a decision should be chosen as the minimum value of the obtained estimates with full agreement, and in this case the threshold value is equal to *p = 3*.

Table 3 is formed from all possible sets of values of features x_1, x_2 and x_3 and the calculated values of their corresponding estimates f_{sf1}, f_{sf2} та f_{sf3}.

Table 3

x	x_2	x_3	f_{sf1}	f_{sf2}		f_{sf3}
1	1	1	1	2		0
1	1	2	1	0		2
1	1	3	3	0		0
1	2	1	2	0		0
1	2	2	2	0		2
1	2	3	4	0		0
1	3	1	2	2		1
1	3	2	1	0		3
1	3	3	3	0		1
2	1	1	0	3		0
2	1	2	0	1		2
2	1	3	2	1		0
2	2	1	1	3		0
2	2	2	1	1		0
2	2	3	3	1		2
2	3	1	0	3		1
2	3	2	0	1		3
2	3	3	2	0		1
3	1	1	0	2		0
3	1	2	0	0		2
3	1	3	2	0		0
3	2	1	1	2		0
3	2	2	1	0		2
3	2	3	3	0		0
3	3	1	0	2		1
3	3	2	0	0		3
3	3	3	2	0		1

As can be seen, the data given in Table 3 make it possible to present the decision-making function in the following form:

$$f_{rj} = \begin{cases} 0, \text{ if } f_{\text{ст}ij} < 3 \ \forall i \\ i, \text{ if } \exists f_{\text{ст}ij} \geq 3 \end{cases} \quad (10)$$

Having determined the value of f_{rj}, according to expression (10), we will obtain a truth table for the decision-making function f_r (Tab.4):

Table 4

x_1	x_2	x_3	f_r	x_1	x_2	x_3	f_r
1	1	1	0	2	2	2	0
1	1	2	0	2	2	3	1
1	1	3	0	2	3	1	2
1	2	1	0	2	3	2	3
1	2	2	0	2	3	3	0
1	2	3	1	3	1	1	0
1	3	1	0	3	1	2	0
1	3	2	3	3	1	3	0
1	3	3	1	3	2	1	0
2	1	1	2	3	2	2	0
2	1	2	0	3	2	3	1
2	1	3	0	3	3	1	0
2	2	1	2	3	3	2	3
2	2	2	0	3	3	3	0
2	2	3	1				

That is, finally the decision-making function f_r is formed and provided in the form of a truth table, and in order to make a decision on recognition, it is necessary to search for a term in Table 4 that corresponds to a set of values of a posteriori information features x_1, x_2, and x_3.

Conclusions

1. The considered method of recognition of SORr differs from known ones in that it is based on the preliminary calculation of estimates of static and dynamic information features using functions of multi-valued logic (*k*-logic) for their description and formalization, which provides an expansion of the possibilities of presenting information features of DRVp from their finite set {0,1,2,…,k-1} instead of {0,1} as for Boolean functions.

2. When solving the tasks of recognition and classification of SORr according to the considered methodology using the functions of multi-valued logic, it is necessary to decompose information features into static and dynamic components, formalize and describe their values, and determine their weighting factors.

3. Precalculation of estimates of static and dynamic features makes it possible to replace the process of calculating estimates with searching for their values in a pre-calculated and compiled table, which will ensure an increase in the speed and reliability of the recognition process as a whole.

4. The use of the proposed methodology will make it possible to make a decision about whether the recognition object belongs to one or another class by calculating the value of only one function, and recalculating the estimates of static and dynamic information features only when the description of the classes of sources and objects of radio monitoring is changed.

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Методологія ідентифікації джерел в об'єктах радіомоніторингу з використанням багатозначності

Проблематика. З постійним розвитком радіоелектронної техніки і телекомунікаційних технологій та появи нових технічних засобів різноманітного призначення, в тому числі й подвійного значення, які мають і оперують вже з новими "нетрадиційними" інформаційними ознаками. Вказані обставини потребують вдосконалення систем їх радіомоніторингу та протидії, з точки зору розвитку високоефективних інтелектуальних систем, які забезпечують збір, обробку, накопичення і використання отриманої моніторингової інформації для прийняття рішення в масштабі реального часу.

Мета досліджень. Підвищення ефективності радіомоніторингу джерел радіовипромінювання здійснюється шляхом декомпозиції їх інформаційних ознак на статичні та динамічні з подальшою формалізацією процесу спостереження та прийняття рішення.

Методика реалізації. Прийняття рішення про приналежність джерела радіовипромінювання до того чи іншого класу здійснюється на підставі попереднього розрахунку оцінок інформаційних ознак для усіх можливих наборів ознак і використання функцій багатозначної логіки для прийняття рішення. Попередній розрахунок, дає можливість збільшити швидкодію роботи алгоритму та приймати рішення про приналежність об'єкта розпізнавання до того чи іншого класу шляхом обчислення значення тільки однієї функції, а перерахунок оцінок статичних і динамічних інформаційних ознак виконувати тільки при змінах описів класів джерел радіовипромінювання.

Результати досліджень. Запропонована методика дозволяє суттєво розширити класи класів джерел і об'єктів радіомоніторингу та забезпечить підвищення швидкодії і достовірності та ефективності процесу розпізнавання в цілому.

Висновки. Прийняття рішення про приналежність джерела радіовипромінювання до того чи іншого класу шляхом використання функцій багатозначної логіки, дозволяє підвищити ефективність системи радіомоніторингу та суттєво розширити клас джерел моніторингу.

***Ключові слова**: радіомоніторинг; інформаційна ознака; розпізнавання; класифікація; оцінка; алгоритм; функції багатозначної логіки.*