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INDICATORS OF INFORMATION FEATURES FOR RECOGNISING THE STATE OF SOURCES AND OBJECTS OF TELECOMMUNICATION NETWORKS AND SYSTEMS

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Background. The majority of modern procedures for the recognition of radio sources and objects are based on the use of binary and multivalued logic, which have low specific features. The essence of the issues is to compare a priori knowledge and a posteriori data coming from the surveillance means and to make a decision on the recognition of a radio emission object. A priori knowledge and a posteriori data are formed both before and during the recognition process on the basis of sets of information features or information signatures. At the same time, when constructing an integral indicator for determining the affiliation and status of sources and objects, it is necessary to know the weighting coefficients of information features, the determination of which is a rather difficult task. Therefore, the issue of determining the weighting coefficients that characterise information features remains an urgent task in the field of statistical radio engineering.

Objective. The purpose of the paper is to select and substantiate a simple and effective method for calculating the weighting coefficients of information features for the implementation of the methodology for recognising radio sources and objects.

Methods. Decision-making on the value of the weighting coefficients of information features of the recognition objects belonging to a certain class is based on the results of calculations using one of the three Fishburne formulae, which, in comparison with the known methods of expert assessments, are very simple and understandable, do not require any additional research and complex calculations.

Results. The procedure is proposed and an example of using the Fishburne method (three formulae) in calculating the value of the weighting coefficients of information features for recognising sources and objects of radio monitoring is considered.

Conclusions. Comparison of the method of calculating the weighting coefficients using Fishburne's formulae with other known methods of expert assessments shows that there is no need to interview experts and process their analysis results; there are no restrictive implementation conditions; it is easy to take into account additional information about the indicators, if necessary; no software implementation with a complex search algorithm is required; it is easy to make any changes as additional information indicators.

Keywords: *sources and objects of radio radiation; radio monitoring; recognition; information features; weighting coefficients; expert assessments; Fishburne formulae.*

Introduction.

It is known [1] that during the monitoring of radio frequency sources (RFS) of telecommunication networks and systems (TCNS) and determination of their classification, affiliation, operational (phase) state and hazard as objects of observation, a number of statistical problems are solved by a number of known methods.

To describe any process or phenomenon, the operation of a complex TCNS system or a single object, a set of indicators (information signs IS) characterising these processes or objects is usually used. Over time and under the influence of various objective and subjective factors, these indicators may change, and according to a random law. That is, it becomes difficult to answer the question of whether a system or object is improving or deteriorating. Therefore, the task of constructing some generalised, reduced to an integral indicator of TCNS recognition and determining their state as objects of observation remains an urgent task.

When solving the problem of building an integral indicator, several stages must be passed. The first stage is the selection of the ISs included in the integral indicator. It can be implemented using many available partial ISs according to known methods and techniques, depending on the content of the main task. Thus, in monitoring TCNS, the most effective is the well-known signature-system method [2], which is based on obtaining a posteriori data on the parameters of radio emission signals ($x_1, x_2, \ldots, x_n,$), comparing them with a priori information on the parameters of input signals (y_1, y_2,..., y_n,) and making a decision on the belonging of the RFS to a particular class of TCNS as an object of observation. Here, the most commonly used signal parameters are operating or carrier frequency, duration and repetition period of signals, frequency deviation and spectrum width, type of modulation and polarisation, etc. It was proved [3] that to obtain the maximum probability of correct recognition of the sources and objects of radio radiation (SORr), their number in a separate signal signature should be m = (4 - 5) units, and the rational number of signatures should be no more than three: k ≈ 3. That is, the number of ISs in the overall signal signature becomes N = m*k = 12 - 15, which ensures the maximum probability of correct recognition of TCNS and decision making.

The second step is to choose a generalising, integral function, which can also be different, but is most often additive or multiplicative. And the third stage is to determine the importance of the selected partial IOs, namely, the weighting coefficients used in the integral functions. That is, each IS has its own importance in the process of recognition and decision-making and is assessed by means of weighting coefficients (r_1, r_2,..., r_n). Therefore, the task of determining the quantitative values of the weighting coefficients of information features arises.

In [4,5], a methodology and algorithm for recognising SORr using the functions of multivalued logic (k-logic) are presented, which consist of the following procedures:

development of information models and detection of IS;

decomposition of information sources into static and dynamic ones;

description and presentation of IS in the form of output data;

calculation of assessment values for static and dynamic features;

determining the weighting coefficients that characterise the informativeness of these ISs;

combining the calculated values of static and dynamic IS assessments;

determining the threshold value and making the right decision.

Recognition and classification of SORr using the algorithm proposed in [4,5] requires the calculation of static and dynamic IE scores for each class of recognition objects, combining the scores for static and dynamic features into a total score, and calculating the probabilities with which the recognition object can be assigned to each of the reference classes. The recognition decision is made based on the analysis of the obtained probabilities. At the same time, the calculation of static and dynamic IS scores in favour of the *i*-th class is carried out using the formulae, taking into account the weighting coefficients rstij and rdnij:

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

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

where: $r_{\text{df}ij}$ and $r_{\text{sf}i}$ are the weighting coefficients characterising the informativeness of the j-th feature assessment when it is taken into account in favour of the *i*-th standard;

$x_{\text{sf}j}$ – the value of the obtained estimate of the *j*-th static feature of the recognition object;

$y_{\text{sf}ij}$ – the value of the j-th static feature of the *i*-th reference;

k_{ij} – coefficient of similarity of the dynamics of changes in the obtained assessment of the j-th dynamic IS when compared with the corresponding feature of the *i*-th reference.

To calculate the similarity coefficient ki between the real and reference values, it is rational to apply the least squares method, according to which [4]:

$$k_i = \sum_{t=0}^{m} \frac{1}{\left(x(t) - y_i(t)\right)^2}\,, \quad (3)$$

where m - the number of available measurements for comparison;

x(t), y(t) - are, respectively, the real and reference values of the IS that dynamically change at time t.

However, the issue of determining the weighting coefficients that characterise the informativeness of the j-th IS assessment when it is taken into account in favour of the i-th standard has not been addressed by the authors. Therefore, the purpose and main content of the article is to analyse and select a method for determining the weighting coefficients of the integral indicator of recognising the state of objects under observation when monitoring radio sources. The authors give their preference to the method based on Fishburne's formulae.

Main part.

One of the simplest and most common ways to determine the weighting factors is through well-known expert evaluation methods [6,7,8]: ranking method; scoring method; numerical method; hierarchy analysis method (HAM); modified principal component analysis (PCA); randomised free variables method (RFM); Fishburne formula method, etc. It should be noted that these methods are well known and have both advantages and disadvantages. Let us briefly and selectively consider their content.

Ranking method. (RM)A group of n experts, specialists in the field under study, expresses their opinion on the importance of m partial ISs. The most important IS indicator is assigned a rank of m, the next most important is $(m - 1)$, and so on, with a rank of 1 being the least important IS indicator. The results of the expert survey are summarised in a table, in the last line of which the sum of the ranks assigned by the experts is recorded, and the weighting coefficients are calculated. The advantage of the method is its computational simplicity, while the disadvantage is the need to interview experts, determine their required number, qualifications, experience, etc.

Scoring method (SM) Unlike the ranking method, here experts assign scores from 0 to 10 depending on the importance of the IE indicator, while it is allowed to assess the importance of the indicator in fractions, and different indicators can be assigned the same score. The weight of each indicator scored by each expert is then determined and weighting factors are calculated. The scoring method is not much more complicated than the ranking method, but it gives more freedom to the experts.

The hierarchy analysis method (BAM) consists in constructing matrices of pairwise comparisons for the indicators of the IO included in different content groups. If higher values of one variable mostly correspond to higher values of the other, and the same is true for lower values, i.e. the variables tend to show similar behaviour, the covariance is positive.

The matrix of pairwise comparisons is square and inversely symmetrical, with one on the main diagonal. The values below the main diagonal are formed by dividing the corresponding values above the main diagonal and vice versa. Each indicator in a row is compared to all indicators in the columns of the matrix. The values of the matrix elements from 1 to 9 represent the nine degrees of importance of one criterion compared to another, with five values being the main values (1,3,5,7,9) and four (2,4,6,8) being intermediate values.

The elements of the matrix a_{ij} are assigned values as follows:

1 - if the indicators are of equal importance;

3 - if the indicator in row i is slightly better than the factor in column j;

5 - if the factor in row i is on average better than the factor in column j;

7 - if the factor in row i is significantly better than the factor in column j;

9 - if the factor in row i is completely dominated by the factor in column j.

If the criterion under analysis is not more but less important than the one with which it is compared, then this ratio is also described by means of nine degrees of comparison, but represented by the inverse values:
1, 1/2, 1/3,..., 1/9.

If we compare the BAM with the previous methods, it should be noted that here: there is no need to collect and interview experts; it is not necessary to know the specific values of the IE indicators; weighting factors can be used in calculations for different time intervals. However, it is necessary to answer the question: how many times more important is one IO indicator than another. And in order to build a matrix of pairwise comparisons, it is necessary to check its consistency, although there are approaches to simplify this procedure.

The modified first principal component (MFC) method is based on determining the integral indicator y as a linear convolution of weighting coefficients and unified values of partial indicators. The MFC method is quite time-consuming. The linear convolution condition to be checked depends on the eigenvalues of the covariance matrix, which, in turn, is determined by specific numerical values of the indicators. Therefore, this condition may be violated over time. In this case, the number of partial indicators included in a particular aggregate indicator, the number of aggregate indicators, and the scheme for calculating the integral indicator SORr must be determined anew each time.

The method of randomised summary indicators (RSI) is based on the construction of a discrete model of uncertainty in the assignment of weighting coefficients, which assumes that each of these coefficients is measured with an accuracy of a finite step $h = 1/n$, which is determined by the natural number 1. That is, the weighting coefficients can only take discrete values. $r_i \in r(n)$. Thus, a randomised vector of weights induced by a random index is created.

Assuming that there is some information on the significance of each indicator, this information can be presented in the form of [9]:

1. Systems of equations and inequalities $R(m, n, 1) = \{ r_r > r_s, r_p = r_q, \ldots\}$ - such information is called ordinal (ordinal) information.

2. Systems of inequalities that define the range of change in weighting coefficients

$R(m, n, 2) = \{ a_i \le r_i \le b_i \}$ - this information is called interval (imprecise) information.

3. Systems that combine ordinal and interval information

$R(m, n, 3) = R(m, n, 1) \cap R(m, n, 2)$ - such information is called non-numerical (ordinal), inaccurate (interval) and incomplete information.

Determining the weighting coefficients using MFC has a good theoretical basis, does not require the involvement of experts and knowledge of the numerical values of the indicators. However, determining the weighting vector requires a software implementation of the method that searches through the valid sets of weighting coefficients, which is a rather complicated task. In addition, it is necessary to establish the dependence of the discrete step on the number of indicators under consideration.

The method of Fishburne's formulae [7, 8] makes it possible to determine the weighting coefficients if some information is known about the indicators. First, they can be ordered in descending order of importance: $x_1 \geq x_2 \geq \cdots \geq x_m$. In this case, the weights form a descending arithmetic progression and can be determined by the formula (Fishburne's first formula):

$$r_i = \frac{2(m-i+1)}{m(m+1)}. \quad (4)$$

For example, for m = 5, the following values are obtained using formula (4):

$$r_1 = \frac{5}{15} = 0{,}33;\ r_2 = \frac{4}{15} = 0{,}27;$$

$$r_3 = \frac{3}{15} = 0{,}2;\ r_4 = \frac{2}{15} = 0{,}13;$$

$$r_5 = \frac{1}{15} = 0{,}07.$$

If you use a simple linear ordering, for example:

$r_1 \geq r_1 + r_2 + \ldots + r_m$;

$r_2 \geq r_3 + r_4 + \ldots + r_m$; $r_{m-1} \geq r_m$,

then in this case the weighting coefficients create a descending geometric progression, and their values are determined by the formula (the second Fishburne formula):

$$r_i = \frac{2^{m-i}}{2^m - 1} \quad (5)$$

For m = 5, the following values of the weighting coefficients are obtained using formula (5):

$$r_1 = \frac{16}{31} = 0{,}52; \quad r_2 = \frac{8}{31} = 0{,}26;$$

$$r_3 = \frac{4}{31} = 0{,}13; \quad r_4 = \frac{2}{31} = 0{,}06;$$

$$r_5 = \frac{1}{31} = 0{,}03.$$

And finally, if the intervals of their possible values (interval ordering relations) can be known with respect to the weighting coefficients:

$$a_i \leq r_i \leq b_i,$$

при $\sum_{i=1}^{m} a_i \leq 1$, $\sum_{i=1}^{m} b_i \geq 1$,

then the so-called third Fishburne formula applies:

$$r_i = a_i + \frac{1-\sum_{i=1}^{m} a_i}{\sum_{i=1}^{m}(b_i - a_i)}(b_i - a_i). \quad (6)$$

Suppose, for example, that for indicators m = 5, the intervals of their possible values are known and are as follows $a_i \leq r_i \leq b_i$:

$\Delta r_1 \in [0{,}4; 0{,}6]$, $\Delta r_2 \in [0{,}3; 0{,}5]$,

$\Delta r_3 \in [0{,}2; 0{,}4]$, $\Delta r_4 \in [0{,}1; 0{,}3]$,

$\Delta r_5 \in [0{,}1; 0{,}2]$.

Then the desired weighting coefficients according to formula (6) will have the following values:

$r_1 = 0{,}4$; $r_2 = 0{,}3$; $r_3 = 0{,}2$; $r_4 = 0{,}1$;

$r_5 = 0{,}1$.

As can be seen from the examples above, all Fishburne formulae (4, 5, 6) are very simple and straightforward, and do not require any additional research or complex calculations.

Conclusions

If we compare the method of calculating weighting factors using Fishburne's formulae with the other methods discussed above, we can say that

- there is no need to conduct expert surveys and process their results;
- there are no restrictive implementation conditions;
- simple consideration of additional information on indicators (ordinal, interval, etc.), if necessary;
- no software implementation with a complex search algorithm is required;
- easy to make any changes as additional information about the indicators.

The listed advantages of using Fishburne's formulae make this method of determining weighting coefficients for solving the problems of classifying and recognising radio emission sources of telecommunication systems and determining the state of objects under observation the most attractive for practice.

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Показники інформаційних ознак для розпізнавання стану джерел та об'єктів телекомунікаційних мереж і систем

Проблематика. Велика більшість сучасних процедур розпізнавання джерел і и об'єктів радіовипромінювання засновано на використанні положень двоїчної і багатозначної логіки, які мають низьку специфічних особливостей. Сутність процесу, шо розглядається, полягає в порівнянні апріорних знань) і апостеріорних даних, що надходять від засобів спостереження, та прийняття рішення про розпізнання об'єкта радіовипромінювання. Апріорні знання і апостеріорні дані формуються як заздалагить, так і в динаміці процесу розпізнавання на підґрунті наборів інформаційних ознак або інформаційних сигнатур. При цьому, при побудові інтегрального показника визначення належності і стану джерел та об'єктів треба знати вагові коефіцієнти інформаційних ознак, визначення яких є достатньо складною задачею. Тому, питання щодо визначення вагових коефіцієнтів, що характеризують інформаційні ознаки, залишається актуальною задачею в галузі статистичної радіотехніки.

Мета дослідження. Вибір і обґрунтування простого та ефективного метода розрахунку вагових коефіцієнтів інформаційних ознак для реалізації методики розпізнавання джерел і об'єктів радіовипромінювання.

Методика реалізації. Прийняття рішення про величину вагових коефіцієнтів інформаційних ознак належності об'єктів розпізнавання до певного класу здійснюється за результатами обчислювання за однієї з трьох формул Фішберна, які в порівнянні з відомими методами експертних оцінок дуже прості та зрозумілі, не вимагають жодних додаткових досліджень і складних обчислень.

Результати дослідження. Запропоновано порядок і розглянуто приклад використання метода Фішберна (трьох формул) при розрахунках величини вагових коефіцієнтів інформаційних ознак розпізнавання джерел і и об'єктів радіомоніторингу.

Висновки. Порівняння методу розрахунку вагових коефіцієнтів за формулами Фішберна з іншими відомими методами експертних оцінок свідчить, що тут: не потрібно мати опитування експертів та обробку їх результатів аналізу; відсутні обмежувальні умови реалізації; просте врахування додаткової інформації про показники (ординальної, інтервальної та ін), якщо виникає така необхідність; не потрібна програмна реалізація зі складним алгоритмом перебору; легко вносити будь-які зміни як додаткові інформаційні показники.

***Ключові слова**: джерела та об'єкти радіовипромінювання; радіомоніторинг; розпізнавання; інформаційні ознаки; вагові коефіцієнти; експертні оцінки; формули Фішберна.*