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RECOGNITION OF REFERENCE SIGNALS AND DETERMINATION OF THEIR WEIGHTING COEFFICIENTS IF AN ADDITIVE INTERFERENCE PRESENTS

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ABSTRACT

Context. The subject matter of the article is the recognition of a reference signal in the presence of additive interference.

Objective. The recognition of the reference signal by the obtained value of its weighting factor in conditions where additive interference is imposed on the spectrum of the reference signal at unknown random frequencies. The task is the development of a method for recognizing a reference signal for the case when the interference consists of an unknown periodic signal that can be represented by a finite sum of basis functions. In addition, interference may also include deterministic signals from a given set with unknown weighting coefficients, which are simultaneously transmitted over the communication channel with the reference signal.

Method. The method of approximating the unknown periodic component of the interference by the sum of basis functions is used. The current number of values of the signal that enters the recognition system depends on the number of basis functions. This signal is the sum of the basis functions and the reference signal with unknown weighting coefficients. To obtain the values of these coefficients, the method based on the properties of the disproportion functions is used. The recognition process is reduced to the calculation of the weight coefficient of the reference signal. If it is zero, it indicates that the reference signal is not part of the signal being analyzed. The recognition system is multi-level. The number of levels depends on the number of basis functions.

Results. The obtained results show that, provided that the reference signal differs by at least one component from the given set of basis functions, the recognition is successful. The given examples show that the system recognizes the reference signal even in conditions where the weighting coefficient of the interference is almost 1000 times greater than the coefficient for the reference signal. The recognition system also works successfully in conditions where the interference includes the sum of deterministic signals from a given set, which are simultaneously transmitted over the communication channel.

Conclusions. The scientific novelty of the obtained results is that a method for recognizing the reference signal has been developed in conditions where only an upper estimate of its maximum frequency is known for the periodic component of the interference. Also, recognition occurs when, in addition to unknown periodic interference, the signals from a given set with unknown weighting coefficients are superimposed on the reference signal. In the process of recognition, in addition to the weighting factor for the reference signal, the factors for the interference components are also obtained.

KEYWORDS: recognition of reference signals, additive interference, weighting coefficients, disproportion functions, basis functions, interference spectrum, Fourier series.

NOMENCLATURE

t is a time;

$y(t)$ is a signal received at the input of the recognition system;

$g(t)$ is a reference signal;

$\eta(t)$ is an interference;

M is a number of basis functions

$f_i(t)$ is a set of given basis functions, i=1, 2,...M;

e_i is a set of unknown coefficients;

k_1 is a weight of the reference signal;

k_2 is a weight of the interference signal;

d is a derivative;

@ is a symbol for calculating disproportion;

h is a step of calculation;

c_i is an unknown coefficient;

N is a number of consecutive measurements;

l is a level;

n is a sequence number of calculating the disproportion at this level;

$D_{l,n}(j)$ is a disproportion;

ω is a circular frequency;

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$@d_x^{(1)}y$ is a disproportion over the 1-th order derivative of y with respect to x. Read as: "at d one y with respect to x".

INTRODUCTION

Recognition of reference signals and estimation of their weighting coefficients occurs when solving many problems. In particular, it is necessary for the recognition of radar signals [1], phonemes in a voice signal [2], modulation for the analysis of an intercepted signal [3], emotions in the creation of intelligent systems [4] in medicine [5, 6], in prosthetics [7], radio monitoring [8, 9], etc. Most of the works are devoted to the detection and recognition of the reference signals if interference is random noise. In particular, it can be a random quasi-stationary periodic process with an unknown current spectral characteristic, about which only an upper estimate of the possible maximum frequency is known. In addition, simultaneously with the periodic process, other deterministic signals from a given set with unknown weighting coefficients can be transmitted over the communication channel.

The cited circumstances testify to the urgency of developing new methods of signal recognition.

The object of research is the process of recognizing a reference signal in the presence of additive interference.

The subject of research is the method and algorithm for recognizing reference signals under the influence of listed types of interference.

The purpose of this work is to develop a method for accurately identifying a reference signal by determining its weighting factor in the presence of additive interference. The primary goal is to address the challenge of recognizing reference signals when the interference consists of an unknown periodic signal and deterministic signals from a given set with unknown weighting coefficients. The research aims to propose a reliable approach based on the use of disproportion functions and the approximation of the unknown periodic component of the interference by a sum of basis functions.

1 LITERATURE REVIEW

Many works are devoted to the detection, recognition, and estimation of parameters of reference signals. Thus, in [8], radio monitoring of radio frequency ranges is carried out to find unoccupied frequency channels in cognitive radio networks. At the same time, signals are detected and recognized under conditions of a priori uncertainty. The noise in the frequency channel is given by the training sample of realizations. The decision rule is implemented in the spectral domain using the discrete Fourier transform. Recognition of phonendoscopy signals in the space of autocorrelation functions and linear prediction coefficients is considered in [5].

In [10], the apparatus of fuzzy sets is used to increase the reliability of positional-binary recognition of signals. Recognition of cyclic signals is carried out by comparing their fuzzy interpretations with the corresponding fuzzy interpretations of reference signals reflecting the temporal arrangement of positional-binary components.

In [11], discrete orthogonal transformation is used for signal recognition. When the investigated signal coincides with the sample, the spectrum of such a transformation contains only one non-zero transformation. It should be noted that the application of the normal transformation to evaluate the similarity of signals based on the obtained coefficients makes it possible to introduce a numerical measure of the evaluation of such similarity. In radio communication, an important task is the recognition of signal modulation. To improve its recognition, a fusion of multimodal features is proposed in [3]. Various functions in the time and frequency domains are obtained as inputs to the network at the signal preprocessing stage. Deep neural convolutional networks are built to obtain spatial features that interact with temporal features.

In [8], to quickly obtain complete information about the characteristics of pulse signals, time and frequency characteristics are obtained. They are mixed in a convolutional neural network for final classification and recognition. Recognition of signals with a time-varying spectrum is considered in [12]. A new radar emitter signal recognition method based on a one-dimensional deep residual shrinkage network is proposed in [1]. In [13], recognition of periodic signals in the presence of additive periodic interference occurs using the first-order derivative disproportionality function.

2 PROBLEM STATEMENT

It is necessary to develop a method for recognizing reference signals and estimating their weighting coefficients when additive interference is imposed on them at unknown frequencies. The interference consists of two parts. The first part is an unknown periodic signal with a random spectrum. We will assume that it meets the requirements for its approximation by a finite sum of basis functions. For example, it can be represented by a finite Fourier series. The second part is the sum of deterministic signals from a given set that can be transmitted over a communication channel simultaneously with a reference signal with unknown coefficients.

First, consider the case where the interference is a random periodic signal that can be decomposed into a finite sum of basis functions. A signal is received at the input of the recognition system:

$$y(t) = k_1 g(t) + k_2 \eta(t). \qquad (1)$$

The interference is quasi-stationary with an unknown current spectrum superimposed on the spectrum of the reference signal at unknown frequencies. Coefficients k_1 and k_2 in (1) characterize the weight of the reference signal and interference, respectively. The values of k_1 and k_2 are unknown.

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$$\eta(t)=\sum_{i=1}^{M}e_i f_i(t). \quad (2)$$

After substituting (2) into (1), we get:

$$y(t)=k_1 g(t)+k_2\sum_{i=1}^{M}e_i f_i(t). \quad (3)$$

It is necessary to find the unknown value of the coefficient k_1 at the reference signal $g(t)$ using the given functions $f_i(t)$ and the current values $y(t)$. The inequality of this coefficient to zero indicates that the reference signal $g(t)$ is recognized in $y(t)$. Its value is the weight of the reference signal. Conversely, if $k_1 = 0$, the reference signal is absent. To solve the problem, it is necessary to specify a set of basis functions. Their number M should not be less than what is needed to approximate the interference. The case when deterministic signals from a given set are added to $\eta(t)$, which are simultaneously transmitted over the communication channel with the reference signal, is easily reduced to the previous one. For this, the list of functions for the decomposition of interference is expanded. $f_{M+2}(t)$, $f_{M+3}(t)$, ... $f_{M+r}(t)$ are added to it, where r is the number of signals superimposed on the reference signal.

3 MATERIALS AND METHODS

Disproportion functions are used to solve the problem [13, 14]. There are the disproportion functions by derivatives, by values, and relative disproportions.

In particular, the disproportion with respect to the first-order derivative of the function $w(t)$ with respect to $x(t)$, where t is a parameter, has the form:

$$z(t)=@d_x^{(1)}y=\frac{w(t)}{x(t)}-\frac{dw(t)/dt}{dx(t)/dt}. \quad (4)$$

In case $w(t)$ can be represented by the sum of known functions $r_1(t)$, $r_2(t)$, ... $r_M(t)$ with unknown coefficients q_1, q_2, ... q_M.

$$w(t)=q_1 r_1(t)+q_2 r_2(t)+...+q_M r_M(t), \quad (5)$$

sequential calculation of disproportion (4) allows the finding of unknown coefficients in (5) [13]. In order to use this property to solve the problem, it is necessary to reduce $y(t)$ (3) to the form (5). For this, we will introduce new notations in (3): $c_i = k_2 e_i$

$$f_{M+1}(t)=g(t), \quad (6)$$

$$c_{M+1}=k_1. \quad (7)$$

Substituting (6) and (7) into (3), we get:

$$y(t)=\sum_{i=1}^{M+1}c_i f_i(t). \quad (8)$$

Thus, the problem is reduced to the application of disproportion (4) according to the algorithm given in [13] to calculate the unknown coefficient c_{M+1} in (8). For this, the current values of $y(t)$ are used. At the same time the coefficients c_1, c_2, ... c_M, which determine the interference $\eta(t)$, are also calculated.

In contrast to [13], the case where $y(t)$ is measured discretely in time with a step h and is represented by the array $y_j=y(jh)$ is considered below. Here $j = 0, 1, 2, ...N–1$. The value of N is determined by the total number of functions involved in the recognition system. In addition to M, the reference function $f_{M+1}(t)$ and $y(t)$ should be taken into account. In this case

$$N\geq(M+1+1)+1. \quad (9)$$

The discrete functions are not differentiable, therefore, instead of disproportion (4), an integral disproportion of the first order should be used [15]. For $w(j)$ and $x(j)$ measured with the same step h, this disproportion has the form:

$$I(j)=@I_x^{(1)}w=\frac{w(j-1+w(j)}{w(j-1)+x(j)}-\frac{w(j)}{x(j)}. \quad (10)$$

Let's present (8) in discrete form, where $f(i, j) = f_i(jh)$, $j = 0, 1, … N–1$:

$$y(j)=\sum_{i=1}^{M+1}c_i f(i,j). \quad (11)$$

To describe the algorithm, it is advisable to consider the simplified case when $M = 4$, i.e., the interference is represented by the sum of only four functions in (11), calculated with step h. Now $f(5,j)$ is the reference function that must be recognized. And it is necessary to determine the coefficient c_5. In this case, the signal (11) has the form:

$$y(j)=c_1 f(1,j)+c_2 f(2,j)+c_3 f(3,j)+ \\ +c_4 f(4,j)+c_5 f(5,j). \quad (12)$$

The algorithm for calculating the coefficients c_i in (12) consists of $(M+1)$ levels. The disproportions (10) $D_{l,n}(j)$ are calculated on each of them.

At the first level, let's calculate the disproportion (10) $y(j)$ with respect to any function from the right-hand side of (12). Let it be $f(1,j)$:

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$$D_{1,1}(j) = @I_{f_i}^{(1)} y = \frac{y(j-1)+y(j)}{f(1,j-1)+f(1,j)} - \frac{y(i)}{f(1,j)} =$$
$$= c_1\left[\frac{f(1,j-1)+f(1,j)}{f(1,j-1)+f(1,j)} - \frac{f(1,j)}{f(1,j)}\right] +$$
$$+ c_2\left[\frac{f(2,j-1)+f(2,j)}{f(1,j-1)+f(1,j)} - \frac{f(2,j)}{f(1,j)}\right] + \cdots \quad (13)$$
$$= c_{m+1}\left[\frac{f(M+1,j-1)+f(M+1,j)}{f(1,j-1)+f(1,j)} - \frac{f(M+1,j)}{f(1,j)}\right].$$

We will also calculate the disproportions of other functions $f(r, j)$ from (12) with respect to $f(1, j)$:

$$D_{1,r}(j) = @I_{f_1}^{(1)} f_r = \frac{f(r,j-1)+f(r,j)}{f(1,j-1)+f(1,j)} - \frac{f(r,j)}{f(1,j)}, \quad (14)$$

where $j = 0, 1, \ldots N\text{–}1$; $r = 2, 3, 4, 5$.

Substitute (14) into (13) and take into account that the first component in (13) is zero. As a result, we get:

$$D_{1,1}(j) = c_2 D_{1,2}(j) + c_3 D_{1,3}(j) + + c_4 D_{1,4}(j) + c_5 D_{1,5}(j). \quad (15)$$

At the second level, in (15), we choose, for example, $D_{1,2}(j)$ and calculate the disproportion (10) of $D_{1,1}(j)$ with respect to $D_{1,2}(j)$:

$$D_{2,1}(j) = @I_{D_{1,2}}^{(1)} D_{1,1} =$$
$$= \frac{D_{1,1}(j-1)+D_{1,1}(j)}{D_{1,2}(j-1)+D_{1,2}(j)} - \frac{D_{1,1}(j)}{D_{1,2}(j)} =$$
$$= c_2\left[\frac{D_{1,2}(j-1)+D_{1,2}(j)}{D_{1,2}(j-1)+D_{1,2}(j)} - \frac{D_{1,2}(j)}{D_{1,2}(j)}\right] +$$
$$+ c_3\left[\frac{D_{1,3}(j-1)+D_{1,3}(j)}{D_{1,2}(j-1)+D_{1,2}(j)} - \frac{D_{1,3}(j)}{D_{1,2}(j)}\right] + \quad (16)$$
$$+ c_4\left[\frac{D_{1,4}(j-1)+D_{1,4}(j)}{D_{1,2}(j-1)+D_{1,2}(j)} - \frac{D_{1,4}(j)}{D_{1,2}(j)}\right] +$$
$$+ c_5\left[\frac{D_{1,5}(j-1)+D_{1,5}(j)}{D_{1,2}(j-1)+D_{1,2}(j)} - \frac{D_{1,5}(j)}{D_{1,2}(j)}\right].$$

Let's also calculate

$$D_{2,r}(j) = @I_{D_{1,2}}^{(1)} D_{1,r} = \frac{D_{1,r}(j-1)+D_{1,r}(j)}{D_{1,2}(j-1)+D_{1,2}(j)} - \frac{D_{1,r}(j)}{D_{1,2}(j)}, \quad (17)$$

where $j = 0, 1, \ldots N\text{–}1$; $r = 3, 4, 5$.

After substituting (17) into (16), taking into account that the first term is zero, we obtain:

$$D_{2,1}(j) = c_3 D_{2,3}(j) + c_4 D_{2,4}(j) + c_5 D_{2,5}(j). \quad (18)$$

Again, we choose any of the components in (18), for example, $D_{2,3}(j)$. Let's calculate the disproportion (10) of $D_{2,1}(j)$ with respect to $D_{2,3}(j)$:

$$D_{3,1}(j) = @I_{D_{2,3}}^{(1)} D_{2,1} =$$
$$= \frac{D_{2,1}(j-1)+D_{2,1}(j)}{D_{2,3}(j-1)+D_{2,3}(j)} - \frac{D_{2,1}(j)}{D_{2,3}(j)} =$$
$$= c_3\left[\frac{D_{2,3}(j-1)+D_{2,3}(j)}{D_{2,3}(j-1)+D_{2,3}(j)} - \frac{D_{2,3}(j)}{D_{2,3}(j)}\right] + \quad (19)$$
$$+ c_4\left[\frac{D_{2,4}(j-1)+D_{2,4}(j)}{D_{2,3}(j-1)+D_{2,3}(j)} - \frac{D_{2,4}(j)}{D_{2,3}(j)}\right] +$$
$$+ c_5\left[\frac{D_{2,5}(j-1)+D_{2,5}(j)}{D_{2,3}(j-1)+D_{2,3}(j)} - \frac{D_{2,5}(j)}{D_{2,3}(j)}\right].$$

Let's also calculate

$$D_{3,r}(j) = @I_{D_{2,3}}^{(1)} D_{2,r} = \frac{D_{2,r}(j-1)+D_{2,r}(j)}{D_{2,3}(j-1)+D_{2,3}(j)} - \frac{D_{2,r}(j)}{D_{2,3}(j)}, \quad (20)$$

where $j = 0, 1, \ldots N\text{–}1$; $r = 4, 5$.

Substituting (20) into (19) gives:

$$D_{3,1}(j) = c_4 D_{3,2}(j) + c_5 D_{3,3}(j). \quad (21)$$

We choose $D_{3,2}(j)$ in (21) and calculate the disproportions (10) with respect to it:

$$D_{4,1}(j) = @I_{D_{3,2}}^{(1)} D_{3,1} =$$
$$= \frac{D_{3,1}(j-1)+D_{3,1}(j)}{D_{3,2}(j-1)+D_{3,2}(j)} - \frac{D_{3,1}(j)}{D_{3,2}(j)} =$$
$$= c_4\left[\frac{D_{3,2}(j-1)+D_{3,2}(j)}{D_{3,2}(j-1)+D_{3,2}(j)} - \frac{D_{3,2}(j)}{D_{3,2}(j)}\right] + \quad (22)$$
$$+ c_5\left[\frac{D_{3,3}(j-1)+D_{3,3}(j)}{D_{3,2}(j-1)+D_{3,2}(j)} - \frac{D_{3,3}(j)}{D_{3,2}(j)}\right],$$

$$D_{4,2}(j) = @I_{D_{3,2}}^{(1)} D_{3,3} = \frac{D_{3,3}(j-1)+D_{3,3}(j)}{D_{3,2}(j-1)+D_{3,2}(j)} - \frac{D_{3,3}(j)}{D_{3,2}(j)}, \quad (23)$$

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After substituting (23) into (22), we get:

$$D_{4,1}(j) = c_5 D_{4,2}(j). \tag{24}$$

Let's calculate the disproportion (10) of $D_{4,1}(j)$ with respect to $D_{4,2}(j)$:

$$\begin{aligned} D_{5,1}(j) &= @I^{(1)}_{D_{4,2}} D_{4,1} = \\ &= \frac{D_{4,1}(j-1)+D_{4,1}(j)}{D_{4,2}(j-1)+D_{4,2}(j)} - \frac{D_{4,1}(j)}{D_{4,2}(j)} = \\ &= c_5\left[\frac{D_{4,2}(j-1)+D_{4,2}(j)}{D_{4,2}(j-1)+D_{4,2}(j)} - \frac{D_{4,2}(j)}{D_{4,2}(j)}\right] = 0. \end{aligned} \tag{25}$$

The equality of $D_{5,1}(j)$ to zero is explained by the presence of a proportional relationship between $D_{4,1}(j)$ and $D_{4,2}(j)$, as can be seen from (24). The unknown coefficient c_5 is calculated from this equation.

$$c_5 = \frac{D_{4,1}(j)}{D_{4,2}(j)}. \tag{26}$$

At the same time, the values of the other coefficients in (12) can be obtained to obtain additional information about the interference and the structure of the signal $y(t)$. This information is necessary to verify compliance with the conditions under which the obtained value of the coefficient c_5 can be considered reliable.

Let's continue the calculation of the coefficients in (12). From (21, 18, 15, 12) we find c_4, c_3, c_2, c_1:

$$c_4 = \frac{D_{3,1}(j) - c_5 D_{3,3}(j)}{D_{3,2}(j)}, \tag{27}$$

$$c_3 = \frac{D_{2,1}(j) - c_4 D_{2,4}(j) - c_5 D_{2,5}(j)}{D_{2,3}(j)}, \tag{28}$$

$$c_2 = \frac{D_{1,1}(j) - c_3 D_{1,3}(j) - c_4 D_{1,4}(j) - c_5 D_{1,5}(j)}{D_{1,2}(j)}, \tag{29}$$

$$c_1 = \frac{y(j) - c_2 f(2,j) - c_3 f(3,j) - c_4 f(4,j) - c_5 f(5,j)}{f(1,j)}. \tag{30}$$

4 EXPERIMENTS

Let's consider the case when the interference consists only of a periodic signal with a frequency limited from above. In (8), it is represented by the sum of harmonic functions:

$$\begin{aligned} y(t) &= c_1\cos\omega t + c_2\sin\omega t + c_3\cos 2\omega t + \\ &+ c_4\sin 2\omega t + \cdots + c_{M-1}\cos\frac{M}{2}\omega t + \\ &+ c_M\sin\frac{M}{2}\omega t + c_{M+1} f_{M+1}(t). \end{aligned} \tag{31}$$

In this case, the coefficients c_1 and c_2 represent the first harmonic, c_3 and c_4 – the second, etc.

To be able to present a periodic interference, one must know its period and, at least approximately, the maximum frequency component. This will allow us to determine the frequency of the first and highest harmonic with the number $M/2$ in (31).

At the same time, the frequency of the highest harmonic with the number $M/2$ can be both equal to the maximum frequency with which the interference is controlled and greater than it.

Let's consider example №1. When solving the problem, it is assumed that the interference $\eta(t)$ has the form (2). It is necessary to make sure that for known functions $f_i(t)$ the proposed algorithm allows obtaining the correct values of coefficients c_i $i = 1, 2, ...M$ in (2). For this, we take $y(t)$ (31) and set the c_{M+1} coefficient to zero at the reference function $f_{M+1}(t)$. As a result, we get:

$$\begin{aligned} \eta(t) &= 0.5\cos(t) - 7.25\cos(2t) + \\ &+ 1.25\sin(2t) - 2.5\sin(5t) + \\ &+ 0.12\cos(7t) + 2\cos(9t) + \\ &+ 0.625\sin(10t) - 3\sin(11t) + \\ &+ 6.75\cos(20t) - 10\sin(20t) = \\ &= 0.5 f_1(t) - 7.25 f_3(t) + \\ &+ 1.25 f_4(t) - 2.5 f_{10}(t) + \\ &+ 0.12 f_{13}(t) + 2 f_{17}(t) + \\ &+ 0.625 f_{20}(t) - 3 f_{22}(t) + \\ &+ 6.75 f_{39}(t) - 10 f_{40}(t). \end{aligned} \tag{33}$$

The frequency band in which the interference is included is approximately known to us. Therefore, it is assumed that its highest harmonic is equal to 25, although, in reality, it is equal to only 20. Thus, the number of functions that determine the interference is $M = 50$. The total number of functions used to determine the coefficients in (33), taking into account $y(t)$, is 51. According to (9), taking into account the absence of a reference function, the number of elements in the discrete representations of the functions is $N \geq (M + 1) + 1 = 52$. Let's take $N = 52$. The step of changing the argument $h = 1$. The results are given in Table 1.

The obtained values of coefficients are following: $c_1 = 0.5$; $c_3 = -7.25$; $c_4 = 1.25$; $c_{10} = -2.5$; $c_{13} = 0.12$; $c_{17} = 2$; $c_{22} = -3$; $c_{40} = -10$. All other coefficients are equal to zero. It is obvious that the obtained results coincide with the values of the corresponding coefficients in (33). The algorithm works correctly.

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Table 1 – Example 1

i	c_i	i	c_i
1	0.5	26	–1.20E–12
2	8.18E–12	27	4.86E–12
3	–7.25	28	1.04E–12
4	1.25	29	4.14E–12
5	2.28E–12	30	2.35E–12
6	2.05E–12	31	–1.98E–12
7	7.18E–12	32	–3.30E–12
8	8.20E–12	33	1.34E–12
9	–1.14E–12	34	–4.15E–12
10	–2.5	35	3.09E–12
11	1.45E–13	36	–1.71E–12
12	–1.00E–14	37	2.38E–12
13	0.12	38	–9.99E–12
14	3.98E–12	39	6.75
15	–6.86E–12	40	–10
16	2.59E–13	41	6.36E–11
17	2	42	–5.45E–11
18	–1.01E–11	43	5.52E–12
19	1.29E–11	44	–3.16E–11
20	6.25E–01	45	–3.70E–11
21	2.57E–12	46	–7.89E–11
22	–3	47	1.21E–11
23	–4.11E–13	48	–2.46E–11
24	1.93E–13	49	1.39E–12
25	8.18E–14	50	–9.09E–12

For comparison, the interference η(*t*) (33) was also decomposed into a Fourier series of 26 harmonics and N = 52. The step of changing the argument $h = 2\pi/N = 0.12083$. As expected, the cosine components for each harmonic coincided with the coefficients for the odd-numbered functions in (33), and the sine components for the even-numbered ones. That is, in this case, the proposed algorithm can be used to decompose the function into harmonics. It should be noted that in the proposed method, $h = 1$ does not depend on N.

In example №2 the case where the frequency range in which the interference is located is incorrectly determined is being investigated. For example, when cos(27*t*) is added to the expression (33), which defines the interference:

$$\begin{aligned}\eta(t) = 0.5\cos(t) - 7.25\cos(2t)\\ +1.25\sin(2t) - 2.5\sin(5t)\\ +0.12\cos(7t) + 2\cos(9t)\\ +0.625\sin(10t)\\ -3\sin(11t) + 6.75\cos(20t)\\ -10\sin(20t) + \cos(27t).\end{aligned} \tag{34}$$

As can be seen from Table 2, all coefficients are not equal to zero and differ from the values in (34). That is, in this case, the algorithm does not work.

Let's consider the example #3. The decomposition of the sum of the reference function $g(t)$ and the interference η(*t*) is considered:

$$y(t) = g(t) + \eta(t), \tag{35}$$

Table 2 – Example 2

i	c_i	i	c_i
1	0.5218	26	–0.00255814
2	–0.0135554	27	–0.00866345
3	–7.47506	28	–0.0321576
4	1.18038	29	–0.0195644
5	–0.0234714	30	0.0329743
6	–0.0409719	31	–0.0267472
7	0.0184056	32	0.00830763
8	–0.083213	33	0.84833
9	–0.0356034	34	0.419396
10	–2.47883	35	0.00274051
11	–0.0093848	36	0.0116143
12	–0.00439558	37	–0.0428529
13	0.119222	38	0.0417336
14	–0.00837845	39	6.49839
15	0.0635089	40	–10.0569
16	–0.0605521	41	0.460666
17	1.97527	42	0.815869
18	–0.000225677	43	–0.0841818
19	–0.0203486	44	0.361305
20	0.606359	45	–0.81944
21	0.0018544	46	0.558422
22	–2.95846	47	0.243344
23	–0.00546663	48	0.0592147
24	0.00449403	49	0.0183457
25	–0.00684171	50	0.0526963

where the interference η(*t*) has the form (33), and the reference function is described by the expression:

$$\begin{aligned}g(t) = 1.5\cos(t) + 3\sin(5t) +\\ +4.75\sin(2t) - 2.5\sin(5t) +\\ +10\cos(7t) + 2.15\sin(10t) +\\ +3.5\cos(15t) + 4\cos(20t) -\\ -10\sin(25t) =\\ = 1.5 f_1(t) + 3 f_2(t) + 4.75 f_4(t) -\\ -2.5 f_{10}(t) + 10 f_{13}(t) + 2.15 f_{20}(t) +\\ +3.5 f_{29}(t) + 4 f_{39}(t) - 10 f_{50}(t).\end{aligned} \tag{36}$$

In this example, the reference function (36) and the interference are in the same frequency range. There are six common basis functions in $g(t)$ as well as in η(*t*). The reference signal can be represented by a finite sum of the same basis functions $f_1(t)$, ..., $f_{50}(t)$ that represent the interference. In fact, the sum of the interference and the reference function (36) is decomposed by means of 51 functions, since $f_{M+1}(t)$ must also be taken into account.

Including $y(t)$, a total of 52 functions are involved in recognition. Therefore, according to (9), $N = 53$ is taken. The results are shown in Table 3. Instead of $c_{51} = 1$, $c_{51} = –0.49484$ was obtained. That is, in this case, the method does not work.

Two important conditions follow from the three examples given:

1. The finite number of basis functions must be sufficient to represent the interference.
2. The basis functions that define the interference should not be sufficient to represent the reference signal. That is, the reference signal must differ by at least one component from the given set of basis functions.

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Table 3 – Example 3

i	c_i	i	c_i
1	2.74225	27	2.80E–11
2	4.48451	28	–8.87E–11
3	–7.25	29	5.23
4	8.35047	30	–1.11E–10
5	–7.28E–11	31	6.45E–11
6	1.84E–10	32	2.51E–11
7	–2.61E–10	33	1.57E–11
8	–2.00E–10	34	1.53E–10
9	6.49E–11	35	3.38E–11
10	–6.23709	36	–6.31E–11
11	1.07E–11	37	6.87E–11
12	–3.48E–12	38	–3.31E–11
13	15.0684	39	–3.31E–11
14	7.12E–11	40	–10
15	2.37E–10	41	–2.02E–09
16	–1.13E–10	42	3.96E–10
17	2	43	2.11E–10
18	3.16E–10	44	–7.62E–10
19	–3.55E–10	45	1.67E–09
20	–3.55E–10	46	1.26E–09
21	8.31E–11	47	1.67E–10
22	–3	48	–1.08E–09
23	–1.33E–11	49	–4.05E–11
24	–1.62E–11	50	–14.9484
25	1.97E–11	51	–0.49484
26	6.26E–12	52	–

Based on this, consider the following examples. In example #4, the interference has the form (33). The reference function differs from (36) due to the addition of cos(30t) and thus satisfies the second condition:

$$g(t) = 1.5\cos(t) + 3\sin(t) + 4.75\sin(2t) - 2.5\sin(5t) + 10\cos(7t) + 2.15\sin(10t) + 3.5\cos(15t) + 4\cos(20t) - 10\sin(25t) + 5\cos(30t). \quad (37)$$

Let

$$y(t) = -1.256 g(t) + 1000\eta(t). \quad (38)$$

The results are given in Table 4.

That is, it is necessary to find the weighting coefficient for the reference signal, which is almost 1000 times smaller than the coefficient for interference. As in the previous case, 52 functions and $N = 53$ take part in the recognition process.

It should be noted that the decomposition of the interference took place. Therefore, the table shows its coefficients from (33), multiplied by 1000. The reference signal was not decomposed.

The coefficient $c_{M+1}(t) = c_{51}(t) = -1.256$ coincides with the coefficient for $g(t)$ in (38). Thus, it was established that $y(t)$ includes the reference signal $g(t)$ with the coefficient –1.256. So, the signal was recognized in the presence of additive interference and its weighting coefficient was determined.

In example #5 consider the case when the signal $g_1(t)$ is added to the periodic interference (33):

$$g_1(t) = 5\sin(6t) - 2.5\exp(-t) + 4.5. \quad (39)$$

Table 4 – Example 4

i	c_i	i	c_i
1	500	27	–1.94E–08
2	–4.54E–09	28	–1.61E–08
3	–7250	29	–1.67E–08
4	1250	30	3.56E–09
5	7.61E–09	31	–1.09E–09
6	–1.47E–08	32	3.24E–09
7	1.64E–08	33	6.85E–10
8	1.44E–08	34	–4.37E–09
9	8.18E–09	35	5.73E–09
10	–2500	36	–5.41E–09
11	3.81E–09	37	1.83E–08
12	2.97E–09	38	–2.65E–08
13	120	39	6750
14	4.66E–09	40	–10000
15	–9.62E–09	41	1.07E–07
16	–4.24E–09	42	–4.83E–08
17	2000	43	–1.51E–08
18	–2.30E–08	44	6.28E–08
19	2.67E–08	45	–7.63E–08
20	625	46	–8.78E–08
21	8.39E–10	47	3.71E–09
22	–3000	48	–1.04E–07
23	3.02E–09	49	–5.06E–09
24	–4.15E–10	50	3.30E–08
25	3.44E–09	51	–1.256
26	–7.02E–10	52	–

It contains a permanent component. The spectrum of the signal $g_1(t)$ goes beyond the frequency band in which the interference is located. Let

$$y(t) = -1.256 g(t) + 1000\eta(t) + 0.725 g_1(t). \quad (40)$$

In addition to the given 50 functions and $y(t)$, two more functions are added. Therefore, according to (9), $N = 54$ is taken. The results are shown in Table 5.

Table 5 – Example 5

i	c_i	i	c_i
1	500	27	–3.73E–07
2	–2.24E–07	28	–1.92E–07
3	–7250	29	–3.08E–07
4	1250	30	–1.26E–09
5	9.74E–09	31	1.31E–08
6	8.01E–09	32	–3.65E–09
7	–7.16E–09	33	5.96E–09
8	8.69E–09	34	1.33E–08
9	9.16E–08	35	1.75E–08
10	–2500	36	–1.13E–08
11	–1.47E–08	37	–3.11E–07
12	–2.63E–08	38	–3.44E–07
13	120	39	6750
14	5.40E–09	40	–10000
15	–6.14E–09	41	–9.08E–08
16	–1.88E–08	42	–2.88E–08
17	2000	43	1.86E–08
18	6.30E–09	44	–6.19E–08
19	3.51E–09	45	1.03E–07
20	625	46	1.60E–08
21	–3.10E–08	47	–1.02E–07
22	–3000	48	–3.90E–07
23	1.13E–08	49	4.58E–07
24	9.07E–09	50	7.11E–07
25	9.65E–09	51	–1.256
26	–1.71E–08	52	0.725

For interference, the same results as in the previous case are obtained. Accordingly, the coefficients are

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obtained for $g(t)$ and $g_1(t)$. $c_{51}= -1.256$ and $c_{52}=0.725$, which coincide with the coefficients in (40). The recognition of the reference signal $g(t)$, the calculation of its weighting coefficient, and the signal coefficient, which is added to the periodic component of the interference, took place. At the same time, the interference practically has a weight 1000 times greater compared to the reference signal.

Example #6 differs from the previous one only in the absence of $g(t)$ in the composition of $y(t)$:

$$y(t) = 1000\eta(t) + 0.725 g_1(t). \qquad (41)$$

As can be seen from Table 6, the coefficient at $g(t)$ $c_{51} = 0$, which indicates the absence of the reference signal in the composition of $y(t)$.

It is also known that $g_1(t)$ with the coefficient $c_{52} = 0.725$ is part of the interference.

Table 6 – Example 6

i	c_i	i	c_i
1	500	27	8.90E–07
2	5.42E–07	28	4.48E–07
3	–7250	29	7.35E–07
4	1250	30	3.11E–08
5	1.33E–08	31	–8.37E–09
6	–2.31E–08	32	–1.07E–08
7	6.26E–08	33	–2.16E–08
8	–1.27E–08	34	–5.11E–08
9	–2.18E–07	35	–3.30E–08
10	–2500	36	1.98E–08
11	4.57E–08	37	8.62E–07
12	7.40E–08	38	8.72E–07
13	120	39	6750
14	–1.81E–09	40	–10000
15	–2.65E–08	41	5.03E–07
16	4.52E–08	42	1.65E–07
17	2000	43	–3.67E–08
18	–2.41E–08	44	1.50E–07
19	4.24E–08	45	–5.27E–07
20	625	46	–7.45E–08
21	6.40E–08	47	2.75E–07
22	–3000	48	8.61E–07
23	–2.58E–08	49	–1.23E–06
24	–2.47E–08	50	–1.66E–06
25	–1.89E–08	51	–2.08E–07
26	4.44E–08	52	0.725

The results obtained for examples 5 and 6 show that the proposed method allows you to recognize the reference signal and determine its weighting coefficient in the presence of combined additive interference.

CONCLUSIONS

The actual problem of recognizing a reference signal in the presence of additive interference is being solved.

The scientific novelty lies in the introduction of a new method of recognizing reference signals and determining their weighting coefficients in the presence of additive interference when the overlapping of the spectrum occurs at unknown frequencies. The interference can include both the random periodic signal and the sum of other deterministic signals from a given set with unknown weighting coefficients. The periodic random component of the interference must meet the conditions for its approximation by a finite sum of basis functions. In particular, it can be represented by a finite Fourier series. To solve the problem, it is necessary to specify a set of basis functions. Their number should not be less than what is needed to determine the interference. At the same time, the reference signal must include at least one component that is not included in this set. In particular, it can be a harmonic that is absent among those specified for decomposition of the periodic component of the interference or a constant component.

The practical significance of this research is evident in its potential application in operational signal recognition systems. Research results indicate that the method works even in conditions where the interference has a weighting coefficient almost 1000 times greater than that of the reference signal. Accurately identifying reference signals amidst additive interference improves signal processing and analysis in various domains.

Prospects for further research involve improving the proposed method in order to identify signs of violation of the conditions necessary for the successful recognition of the reference signal.

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РОЗПІЗНАВАННЯ ЕТАЛОННИХ СИГНАЛІВ ТА ВИЗНАЧЕННЯ ЇХНІХ ВАГОВИХ КОЕФІЦІЄНТІВ ПРИ НАЯВНОСТІ АДИТИВНОЇ ЗАВАДИ

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АНОТАЦІЯ

Актуальність. Розв'язана актуальна задача є розпізнавання еталонного сигналу при наявності адитивної завади.

Мета. Розпізнавання еталонного сигналу по отриманому значенню його вагового коефіцієнту, коли адитивна завада накладається на спектр еталонного сигналу на невідомих випадкових частотах. Завдання: розробити метод розпізнавання еталонного сигналу для випадку, коли завада складається із невідомого періодичного сигналу, який може бути представлений кінцевою сумою базисних функцій. В заваду можуть також входити детерміновані сигнали із заданої множини з невідомими ваговими коефіцієнтами, які одночасно із еталонним передаються по каналу зв'язку. Для розв'язання задачі застосовується метод апроксимації невідомої періодичної складової завади сумою базисних функцій. Поточна кількість значень сигналу, що поступає на систему розпізнавання залежить від кількості базисних функцій. Цей сигнал є сумою базисних функцій і еталонного сигналу із невідомими ваговими коефіцієнтами.

Метод. Для отримання їх значень вагових коефіцієнтів використовується метод, що базується на властивостях функцій непропорційності. Процес розпізнавання зводиться до обчислення вагового коефіцієнта еталонного сигналу і порівняння його з нулем. Система розпізнавання багаторівнева. Кількість рівнів залежить від кількості базисних функцій.

Результати. Отримані результати свідчать, що якщо еталонний сигнал відрізнятися хоча б на одну складову від заданої множини базисних функцій, розпізнавання відбувається успішно. Приведені приклади свідчать, що система розпізнає еталонний сигнал навіть в умовах, коли ваговий коефіцієнт завади майже в 1000 раз перевершує коефіцієнт при еталонному сигналові. Система розпізнавання працює успішно також в умовах, коли завада включає суму детермінованих сигналів із заданої множини, які одночасно передаються по каналу зв'язку.

Висновки. Наукова новизна отриманих результатів в тому, що розроблено метод розпізнавання еталонного сигналу в умовах, коли для періодичної складової завади відома лише оцінка зверху її максимальної частоти. Також розпізнавання відбувається, коли крім невідомої періодичної завади на корисний еталонний сигнал накладаються сигнали із заданої множини з невідомими ваговими коефіцієнтами. В процесі розпізнавання крім вагового коефіцієнту для корисного еталонного сигналу також отримуються коефіцієнти для складових завади.

КЛЮЧОВІ СЛОВА: еталонний сигнал, завада, розпізнавання сигналу, ваговий коефіцієнт, функції непропорційності, базисні функції, конечний ряд Фур'є.

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