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ENHANCEMENT OF NOISE IMMUNITY AND INCREASE IN DATA TRANSMISSION SPEED IN TELEMETRICAL COMMUNICATION SYSTEM

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Abstract: Effective monitoring of physiological parameters indicating the state of a human being under extremal conditions is highly important in order to provide fast and efficient medical care in acute cases. Thus, development of biotelemetry technologies is a matter of topical interest. The paper is concerned with the methods of enhancement of noise immunity and increase in data transmission speed in a telemetry communication system on the basis of a new discrete spectral transform in an oriented basis.

The proposed idea consists in using matched filters with the transient characteristics coinciding with the basis functions of the proposed spectral transform in an oriented basis. This new approach allows enhancing of noise immunity and reducing of computational complexity in comparison with widely known methods.

Key words: biotelemetry technologies, noise immunity, data transmission, telemetry communication system, spectral transform

1. Introduction

The problem of effective monitoring and control of the parameters that characterize, for example, the physiological state of a man in tactical medicine [1], special climatic conditions or technical state of autonomous objects is extremely urgent, especially when the decision-making speed is a key factor for providing on-time medical aid or maintaining the given environmental conditions required to ensure the performance of technical equipment.

Despite a variety of the existing approaches to solving this problem, increasing the speed and efficiency of on-line functioning remains a challenging direction in order to make timely and correct decisions. The general requirement to all the methods is to provide reliable data communication in terms of noise immunity against the noise from specialized transceivers, electronic systems and other signal distortions that may occur.

Applying new spectral transforms to data collection, coding/decoding, processing, analysis, noise-immune data transmission will improve the decision-making reliability and speed, and thus increase the effectiveness of monitoring and control. This will provide a more significant increase in the processing speed and transmission reliability in noisy environments than the traditional methods of analysis.

2. Choosing a mathematical apparatus

For proper and timely data transmission in a multiuser communication system, it is advisable to use a broadband technology of Code Division Multiply Access (CDMA) [3,4]. This allows a high degree of channel multiplexing, and accordingly, expands communications capabilities and network performance. Spreading an information signal spectrum using the technology of Direct Sequence Spread Spectrum (DSSS) can improve the noise immunity of transmission.

The basis of the CDMA technology is the property of mutual orthogonality. Walsh sequences are usually used as channel codes for spectrum spreading and multiplexing. However, the sequences composed of basis functions of the spectral transform in an oriented basis (OB-transform) simplify the signal processing algorithms and can significantly increase their operation speed (due to the fact that approximately 30% out of the elements of the matrix of basis functions are zero elements) [5].

3. The proposed discrete transform in an oriented basis

The OB-transform was developed as the modification of discrete functions transform on finite intervals – so called "spectral finite interval transform" (SFI-transform) [5] that, in turn, was obtained from the well-known Hartley and Vilenkin-Chrestenson transforms [2, 6]. The OB-transform was obtained from the SFI-transform by orienting the axis of its basis functions at some angle that determines a position of basis functions vector on the complex plane according to the features of the analysis objectives. As a result, different values of the axis orientation angle leads to various transforms.

The purpose of the new transform development is obtaining a mathematical method of spectral transform with reduced number of different values of its basis functions defined on a finite discrete interval with the length $N = m^n$, where m is a prime number; n is an integer.

A direct OB-transform has the following form:

$$Y(n) = \sum_{x=0}^{N-1} y(x) \cdot j_d(n, x), \qquad (1)$$

where $y(x)$ is an original function; $Y(v)$ is its image (spectrum); either function is determined by $N = m^n$ discrete values. The functions' arguments x and v are represented by the expressions:

$$x = \sum_{s=1}^{n} x^{(s)} \cdot m^{n-s}; \qquad (2)$$

$$v = \sum_{s=1}^{n} v^{(s)} \cdot m^{n-s}; \qquad (3)$$

and take the integer values in the range from 0 to $N-1$, where $x^{(s)}$ and $v^{(s)}$ are the bit components of an m-ary representation of x and v;

$$j_d(n, x) = \cos\left[\frac{2p}{m}\sum_{s=1}^{n} n^{(s)} x^{(s)}\right] + A \sin\left[\frac{2p}{m}\sum_{s=1}^{n} n^{(s)} x^{(s)}\right] -$$

are the basis functions of the direct OB-transform; $A = tg\, a$ is the factor determining the orientation of the transform axis:

$$A = tg \frac{2p\, i}{m}, i = 1, \mathbf{K}, m-1.$$

The inverse OB-transform can be obtained from the requirement of orthogonality of its basis functions to the basis functions of the direct OB-transform in the form of the following expression

$$y(x) = \frac{1}{N}\sum_{n=0}^{N-1} Y(n) \cdot j_r(n, x), \qquad (4)$$

where $j_r(n, x)$ are the basis functions of the inverse OB-transform.

In a particular case at $m = 3$, the basis functions of such OB-transform take strictly integer values that is especially valuable when implementing the computing algorithms of spectra and originals, correlation and convolution of functions for integer processors and microcontrollers. Thus, if the interval length is $N = 3$, the matrices of the direct F_d and inverse F_r transforms consist only of the values 0, 1, -1, -2:

$$F_{d3} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{bmatrix}, \quad F_{r3} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 0 \\ 1 & 0 & -1 \end{bmatrix}.$$

If it is necessary that the interval N be increased, then the matrices of greater dimension can be found using the recursive formulas; therefore, they are composed of the same elements. This fact eliminates multiplications (binary implementation of multiplication by 2 is equivalent to the left shift by one digit). This greatly simplifies the calculations and leads to increasing the data processing speed. Thus, applying the OB-transform in data communication systems can significantly improve the system performance. The fact that about 30 % of the elements of the basis matrix (i.e. the values of the basis functions) are zero elements enables to simplify the algorithms of digital signal processing and increase the speed and number of channels as compared with the known systems.

We should also draw attention to the possibility of using the existing digital communication hardware while implementing the OB-transform algorithms, since it is fully compatible with the approach to the implementation of transmission methods based on the basis functions of Walsh transform [2]. So, it is not necessary to employ different controllers or microprocessors. Changing the algorithm would be enough to increase the calculation speed while fulfilling the same tasks.

Due to the orthogonality of OB-transform matrices and the possibility to change the orientation angle of the axis to different values, there is a whole family of transforms in the oriented basis [5]. For $m = 3$, there are four such possible transforms (OB1-OB4) [6]. The algorithms for generalized, multi-dimensional and rapid transforms were also developed [5].

Fig.1 illustrates a comparison of different spectral methods including SFI, Walsh, and OB [2, 5, 6] in terms of the number of computational operations depending on the interval length. As it can be seen from Fig. 1, the fastest transforms are OB2 and OB4 for $m = 3$ followed by Walsh transform, OB1 and OB3 for other values of m, and then the SFI transform [5].

All the other known methods (e.g. Fourier and Hartley) are much slower even while realizing fast algorithms [6].

The relative complexity of OB-transforms is 44,3–95 % of the relative complexity of Walsh transform for commensurable values of the interval lengths of the transforms. The property of orthogonality holds for the basis functions of OB-transform [6], as well as for Walsh transform. Bearing this in mind, it is reasonable to replace the basis functions of Walsh transform in CDMA systems by the basis functions of OB-transform [6] for the purpose of improving the performance.

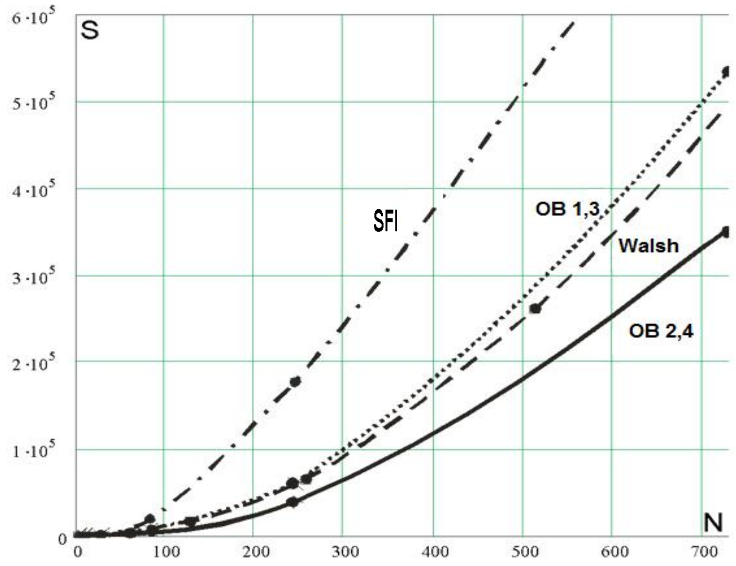

Fig. 1. Dependencies of the number of computational operations when calculating the originals and spectra for different spectral transforms.

So, the basic functions of OB-transform can be used as channel codes able to increase the number of channels, as compared to the CDMA-systems which use Walsh transforms, in $\frac{3^n}{2^n}$ times, where 3^n and 2^n are the numbers of the basis functions used for encoding in case of OB- and Walsh transforms, respectively [6].

Thus, the OB-transform can be effectively used to:

- ensure the noise immunity of signal transmission;
- increase the number of channels as compared with the known systems.

The advantage of this approach is the feasibility to implement the OB-transform on the same hardware components that are used for Walsh transform. Therefore, the communication system can be updated solely by reprogramming.

4. Implementation of matched filters

The basic elements of CDMA data transmission systems are digital matched filters. A digital matched filter is a filter whose impulse characteristic coincides with one of the orthogonal basis functions of the direct OB-transform.

Let the impulse characteristic of a filter be one of the basis functions $j_d(v,x)$ of the inverse OB-transform at $v = p$, and one of the basis functions (coinciding or not with the impulse characteristic) be transmitted.

The matrix of the basis functions of the direct OB-transform [5] contains only two values (-2 and 1) and can be transmitted by such known modulation techniques as phase-shift keying.

If the function $S_{in}(x) = j_d(v,x)$ at $v = q$ is delivered to the input of the matched filter, the filter response $S_{out}(x)$ is described by the following formula:

$$S_{out}(x) = \sum_{t=1}^{N-1} j_d(q,t)\, j_r\left(p, \sum_{s=1}^{n}\left(t^{(s)} \underset{m}{q}\, x^{(s)}\right)\right), \quad (5)$$

where $\underset{m}{q}$ is the symbol of the operation of subtraction by the module m.

Using the shift theorem, an expression for the output signal can be obtained in the following form:

$$S_{out}(x) = \begin{cases} 0, & p \neq q; \\ N \cdot j\,(p, \underset{m}{q}\, x), & p = q. \end{cases}$$

Thus, the filter matched with one function $j_r(p,x)$, passes the function $j_d(p, \underset{m}{q}\, x)$ without distortion and does not pass any other basis function $j_d(v,x)$ i.e. it is the best detecting filter. With any other form of the input signal being fed to the input of the filter, the matched filter is considered an optimal detecting one, maximizing the RMS of the noise-to-signal ratio [5]. If the basis functions of OB-transform are used as channel codes, the output signal of the matched filters is determined by the expression (1). Such matched filters can be effectively used for detecting of signals in a noise background. They can be constructed on the basis of delay lines. This implements an m-shift of digits of the filter impulse characteristic.

5. Single-channel transmission system

In a communication system, the simplest task is to ensure a noise-immune data exchange between two nodes - network subscribers. A block diagram of such a system is shown in Fig. 2. It comprises a control unit of OB-function generators, OB-function generators, a modulator-demodulator, N matched filters, and a unit for the analysis of the matched filters output.

In the transmitting system (i.e. transmitter), each of the possible control signals corresponds to one of thebasis functions of OB-transform. The resulting code sequences are modulated by the modulator and transmitted to the link line.

The transmitted control signal *1* enters the receiving system (i.e. receiver) via the link line. It is delivered to the inputs of several matched filters through the demodulator. The number of the matched filters in the receiver equals the number of the basis functions of OB-transform in the transmitter.

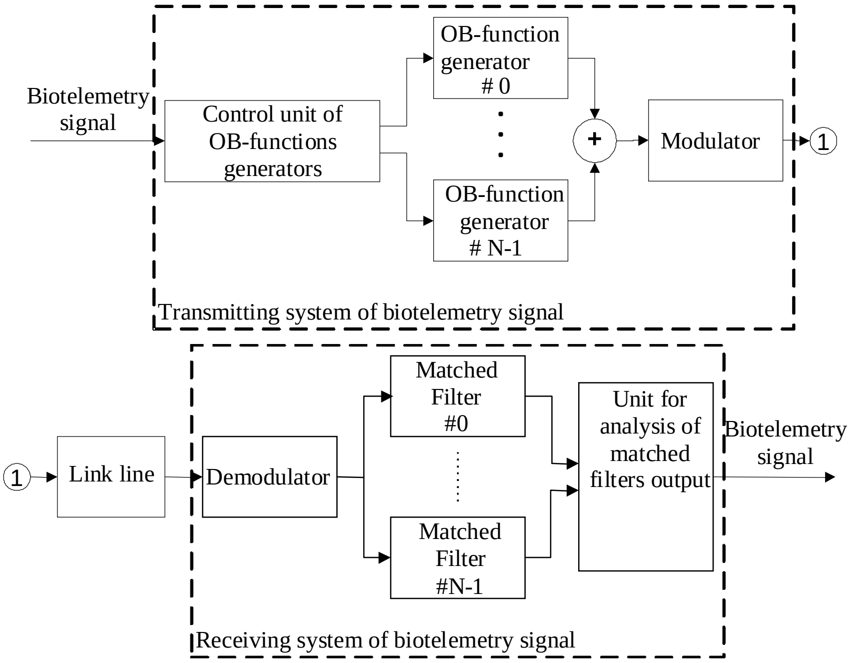

Fig. 2. Block diagram of a single-channel transmission system.

Without noise, all the matched filters outputs, except one of them, have zero output signals. In case if the noise level does not exceed an allowable level, the values of all the output signals, except one of them, are below a certain threshold value. A logical device, which is a part of the receiver, determines the correspondence between the number of the matched filter with the output signal that is greater than a certain threshold value, and one of the possible control signals. Thus, the receiver output waveform coincides with the waveform generated by the control system, but it is shifted over time by N digits. If nothing but noise is present at the receiver input and its level does not exceed an allowable level, the values of output signals of all the matched filters are below a certain threshold value.

If the number of control signals is greater than N, then each of the possible signals is brought in correspondence with some sequence of the OB-transform basis functions. The principle of each sequence transmission remains the same.

6. Multi-channel transmission system

Receiving noise-like signals by application of matched filters with the impulse characteristics based on the discrete spectral transforms allows several different noise-like signals to be received simultaneously. The main requirement is mutual orthogonality of all noise-like signals in the ensemble used by the transmission system. Thus, it becomes possible to develop a multi-channel system with large number of channels for transmitting a biotelemetry signal.

Each channel uses a carrier signal which is orthogonal to all other carrier signals. To ensure the orthogonality, it is proposed to generate carrier signals with the waveform determined by the basis functions of direct OB-transform that are orthogonal to the basis functions of reverse OB-transform. The number of channels in this case is determined by the order of the OB-transform matrix (the number of digits in a basis function).

7. Increase in the transmission speed of control signals in a single-channel system

High speed of data exchange in a system of on-line monitoring, data transmission and control is one of the most critical requirements. The transmission speed can be increased, while maintaining high noise immunity, by implementation of multi-channel transmitters and receivers with matched filters for single-channel signal transmission.

The block diagram that illustrates the principle of the system is shown in Fig. 3. A message symbol generated by the control system enters a data packet forming unit. A single-channel signal - a binary sequence representing the data packet before getting to a multi-transmitter (TS) – is converted into a parallel multi-channel signal using a shift register (SR1) (Fig. 3). The signals from SR1 outputs are delivered to the inputs of the multichannel transmitter that uses the CDMA technology (see Fig. 2). Afterwards, the multi-channel signal gets to a link line (LL). The receiver (RS) gets the multi-channel signal from the link line and detects all the transmitted signals using a parallel array of matched filters. Then, by means of a shift register (SR2), the parallel signals are converted into a single-channel signal.

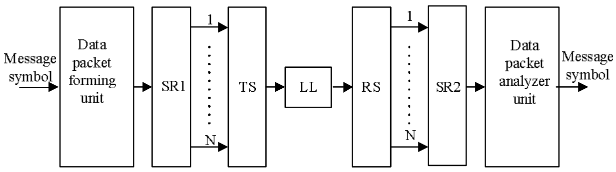

Fig. 3. Parallel transmission of a single-channel signal.

The resulting binary sequence is processed by a data packet analyzer unit and is received by the control system on the other side.

Owing to the method application, the single-channel transmission speed is N times greater than the rate of transmission of separate signals at SR1 output.

8. Conclusion

In telemetry communication systems, the implementation of code division multiple access (CDMA) technology with the spectrum spreading on the basis of OB-transform increases the level of noise-immunity and data transmission speed.

The speed of digital matched filtration algorithms based on the OB-transform increases in comparison with other known methods, for example, Walsh transform (see Fig. 1).

If the OB-transform is employed, the number of channels, as compared to the CDMA system that uses the carrier signals with the waveform determined by the Walsh basis functions, rises $\frac{3^n}{2^n}$ times, with 3^n and 2^n being the numbers of basis functions used to encode in OB-transform and Walsh transform, respectively. There is a possibility to implement the OB-transform on the same hardware components that are used for Walsh transform. Therefore, the communication system can be updated merely by reprogramming.

The application of multi-channel transmitters and receivers for transmitting of single-channel signals provides an N times increase in the transmission speede (where N denotes the number of parallel channels) in comparison with the transmission speed of separate signals.

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ПІДВИЩЕННЯ ЗАВАДОСТІЙКОСТІ ТА ШВИДКОСТІ ПЕРЕДАВАННЯ ДАНИХ В ТЕЛЕМЕТРИЧНІЙ КОМУНІКАЦІЙНІЙ СИСТЕМІ

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Ефективний контроль за фізіологічними параметрами стану людини в екстремальних умовах є надзвичайно актуальним. Важливим кроком на шляху підвищення швидкості надання медичної допомоги та реагування на загрозу здоров'ю людини є впровадження технології біотелеметрії. Стаття присвячена методам підвищення завадостійкості та швидкості передавання даних телеметрії в системі зв'язку на базі розробленого авторами нового математичного апарату – дискретного спектрального перетворення в орієнтованому базисі.

Запропонована авторами ідея полягає у використанні узгоджених фільтрів з перехідними характеристиками, які збігаються з базисними функціями цього

перетворення. Впровадження технології передавання даних на базі перетворення в орієнтованому базисі підвищує завадостійкість та зменшує трудомісткість алгоритмів, що її реалізують, у порівнянні з широковідомими аналогічними методами.

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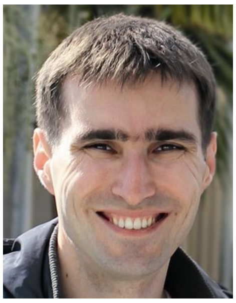

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