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INFORMATION ELECTRONICS: TECHNOLOGIES OF THE BIOMEDICAL SIGNAL PROCESSING REVIEW

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Abstract. The references to research and applications of some perspective methods of processing signals of physical (including biomedical) origin are represented. The condition of using effective information technologies in diagnostic systems in Ukraine is analyzed. The discrepancy between the development of domestic electronic systems and the modern world tendencies of processing technologies related to the diagnostic information is noted.

Keywords: Signal processing, information electronics, computer diagnostics, information technologies.

Introduction

The purpose of the article is the review of literature on actual branch of signal processing (in particular the signals of biomedical origin) and on electronic information systems (for defining certain world tendencies of the development in this branch), as well as the analysis of the state of applying modern perspective information technologies in diagnostic systems in Ukraine.

1. Actual problems of signals processing

The research in the area of electronic information systems, modelling of signals and systems at continuous time, at discrete time and in hybrid systems at mixed time, as well as other pressing questions on information electronics always has been in the centre of attention of the experts in the branch of the theory and practice of such signal processing [1]. Certainly, in this review it is necessary to guide the reference to the works [2,3] devoted to the theory, design and application of information systems for solving problems of signal processing including signals of biomedical origin. In the last years experts have paid certain attention to digital signal processing involving channels with multifrequency (multihigh-speed) digitization (multirate channels). The list of the articles devoted to these problems can be found in the reviews by R. E. Crochiere, L. R. Rabiner [4] and P. P. Vaidyanathan [5]. Except the classical monograph by R. E. Crochiere and L. R. Rabiner [6] also the fundamental monographs of P. P. Vaidyanathan [7], N. J. Fliege [8] and B. V. Sutter [9] have been published.

The approximation of signals by simple functions or rows of such functions has been an actual problem for mathematics and the directions of engineering in which it is applied. First of all, it may serve as a tool for the creation of new highly effective technical products, devices and software for signal and image processing. Fourier transform has appeared to be the most outstanding achievement of mathematics in this direction. This tool for function approximation has undergone the development for a long time from 1754 (Bernoulli) until now. During this period outstanding mathematicians and physicists (Euler, Fourier, Dirihle, Poincare, Hertz, Andreev, Fleming, Mandelstam and others) have made essential contribution to it. At the same time the use of the signals with a local characteristic property such as, for example, biomedical signals has underlined basic disadvantages of the Fourier analysis and synthesis:

- Integrals included into formulas for Fourier coefficients are complicated for calculations (they contain factors of fast oscillation and require a large number of the integrations by intervals of integration.
- The application of the complex methods of the adaptive integration to control errors during the process of calculations using the built-in functions essentially reduces the integration;
- The basic function of Fourier-transform is of little use for the notation, processes and systems of nonstationary signals in condition of limiting the number of the terms of a series or a spectrum expansion;
- Gibbs effect (especially in places of function discontinuity and in especial points) is impossible to be eliminated by increase in the number of harmonics.

Fast Fourier Transform (FFT) allows for substantially reducing the time of spectral analysis and synthesis (due to the use of the special technique of combinations of readout functions, multiplied on factors, which oscillates, and taking into account periodicity of trigonometric functions) but does not reduce an error of calculations.

At last, continuous Fourier transform for any arbitrary signal enables only the estimation of the density of signal energy in some narrow band. It causes the main disadvantage of the Fourier transform: an integrated estimation of all frequency components of a spectrum irrespectively of the time of their existence. The recent use of complex signals in the research and practice of complex signals (namely signals of biomedical origin: they differ in the big base of a signal: $BT >> 1$, where *B* – spectral width, *T* – signal duration) has shown, that the classical Fourier transform poorly represents the dynamics of such signals. The situations are possible when practically identical spectral portraits (amplitude spectrums) correspond to signals with essentially different time portraits.

Therefore transition to the spectral – time portraits of signals, that is, their representation in a time-frequency plane, is an analysis stage of solving determined processes limited in time. The short-time Fourier transform (Short Time Fourier Transform – STFT) serves as the analytical base of such transition. By the definition:

$$STFT_X^{(y)}(t,f) = \int_{-\infty}^{\infty} x(t')e^{-j2\pi ft'}\gamma^*(t'-t)dt', \quad (1)$$

where *x (t)* – a signal; - $\gamma^*(t)$ time function (a time window, or a data window), generally complex; * - a symbol of complex conjugation.

It is essentially important to point out using causal windows in [10]. It corresponds to calculation through the instant value of a signal, previous to the moment of observation. It indicates the observation of these spectrums by physically possible analyzers. The computer realisation of a spectral analysis does not necessary demand causality windows $\gamma*(-t)$ because the signal realisation is stored in the computer memory and it is possible to observe in a window not only the "past" of the signal but also its "future".

The short-time window Fourier transform mentioned above does not solve all problems of time-frequency representation of signals: first, it is impossible to receive high resolving power both for time and for frequency ($\Delta t\Delta f \leq 1/4\pi$); secondly, the unique basic function, namely a sinusoid, has itself the disadvantages noted above. The specified disadvantages can be eliminated by the transition to adaptive window transformation in which the window width can be adapted to the features of a signal, and the basis of expansion can meet following demands: it is localised in time (space); it is capable to be shifted in time (space); it is scaled; it has the limited (local) frequency spectrum. The orthogonal basis essentially facilitates the analysis, gives the possibility for reconstruction of signals and allows for using algorithms of fast transforms.

The technology of a signal expansion with the basis designed from certain function, – the wavelet (satisfies "waves" [11] by scale changes and shifts) meets the specified demands. According to the name of basic function this information technology has received the name of "wavelet-transform" (WT).

During the current period there exists the unconditional and actual necessity for the active introduction of methods and wavelet-analysis agents to the engineering practice and scientific research. The synthesis of wavelet-samples from the wide list of models of one-dimensional signals which are widely mentioned in the literature sources on various directions of modern informational electronics [12] is one of the practical steps towards this task.

One means of information technologies based on wavelet-transforms is multiscaling (or multiresolution) the analysis offered by S. G. Mallat and Y. Meyer in the year 1986 [13]. Presently its successful application in computer medical diagnostics [14] is well-known. In work [15] the examples of processing real biomedical signals resulted in [14] are executed.

The orthogonal transform of initial images is a key procedure in modern digital image processing including biomedical one. Among the most known there are different revisions of so-called separate unitary transform (SUT). Among some orthogonal transforms of digital images the so-called singular transform can be separated [16].

It is also expedient to remind the basic results of the development of fast algorithms of signal processing. Their brief but comprehensive analysis is given in [17]. Taking into account that the algorithm of the fast Fourier transform, its design considered by J. Cooley and J. Tukey [18], has found its application for the effective calculation of the discrete convolutions, the subsequent development was extended by practical applications of digital signals processing (DSP) for which the procedure of the machine computing discrete orthogonal transformations (DOT) is one of the fundamental data problems. Before such applications it became possible to realize the following: systems of a sound location, seismic information processing, computer tomography, non-destructive control, image processing, and so forth. The subsequent development of research in this branch is described in [19], and works [20] are considered as the theoretical base of fast algorithms for orthogonal transformations. The fast algorithms of calculations are also applied in the new types of discrete transformations appeared during the last decades. Intent the Haar transform, integrated Haar transform, cosine transform, slent-transform and other transformations are known [21]. It is not improbable that the expansion using a wave-wavelet [22] can essentially supplement the expansion into a trigonometric series and Fourier transform.

The discrete Karunen-Loev transform is one of the effective analytical tools of modern applied statistics generally, and of computer medicine (telemedicine) in particular. In the world practice this transformation is applied to the analysis of the diagnostic material with the known method of the main things as a component and the modern computer version of the factorial analysis.

Last years are marked by rising of the attention of experts in signal processing to Gabor transform, suggested more than 50 years ago. The Gabor transform of analogue signals is in detail considered in [23]. Meanwhile, the transformations corresponding to computer signal processing are discrete both in time and in frequency. The Gabor transform of time discrete signals is an example of such a transform.

During the last decade experts actively use the orthogonal basis in signal processing of any physical origin (in particular, biomedical) (Fourier, Wolsh, Haar, ets.). By the way, the authors of the most perspective information technologies, as a rule, use other analytical software (tools): biorthogonal bases and frames [24].

In the review it is also expedient to mention some approaches to solving problems of information processing. The analysis of the works devoted to morphological image transforms (MIT) is quite indicative. Mathematical morphology is used in the systems of biomedical image processing, the systems of the computer sight of robots, the structural analysis of signals, submicroscopy, metallography, geology, geography, remote sounding. The problems of nonlinear filtration, detecting of the edges of images, noise elemination, form representations, recognition, skeletonising, coding of images are solved using the methods of mathematical morphology. There are more than 150 editions (mainly English-speaking) on the problems of morphological image transforms. The translation of the fundamental work by P. Maragos and Schafer [25] into English owing to a difficult manner of the statement only for some time has distracted the attention of experts from exclusively interesting and extremely fruitful instruments and methods of processing biomedical signals.

But recently in the world the majority of the problems of digital processing of signals, that is, the images of biomedical origin, are solved by the means of the wavelet-analysis which due to the properties mentioned above answers the question of image nature better, than periodic functions.

2. Wavelet principles of the construction of diagnostic systems for the analysis of biomedical signals

It is known, that efficiency and effectivity of any treatment first of all depends on fidelity and timeliness of the diagnosis. Today in the world the considerable quantity of the diagnostic equipment allowing for the localization (as much as possible authentically) the area of pathological changes in an organism has been approached. The basic component of such equipment is the analyzer of biomedical signals in which for signal processing a modern mathematical apparatus is used. The most perspective tools are the widely known analyzers based on wavelet-technologies. A wavelet approach is ideal for the analysis of non-stationary signals (that is, the biomedical signals of any physical nature). The short-list of the applications of wavelet-technologies for solving problems of diagnostics looks as follows.

I. In the systems of the analysis of one-dimensional signals

1. **In electrocardiography** for solving the problems of automatic recognition [26], classification [27] and compression of [28] cardiograms, the detection of arrhythmic heartbeat intervals [29], the analysis of ventricular late potentials [30].

2. **In phonocardiography** for the analysis of pathological changes in a phonocardiogram [31], the diagnosis of coronary heart disease [32] and the compression of the phonocardiogram [33].

3. In the reanimation systems of invasive pressure measurement for the estimation of pulmonary capillary pressure [34].

4. **In electroencephalography** for allocation and real time analysis of pathological frequency dependent signs of EEG-signals while carrying out surgical operations and intensive therapy [35], the estimation of caused potentials [36], the classification of EEG [37] and the analysis of cortical activity of the patient’s brain under general anaesthesia [38].

5. **In ultrasonic dopplerography** for blood flow velocimetry [39], signal denoising [40], the detection of embolic signals [41].

6. **In laser dopplerography** for the diagnosis of the occlusion of peripheral arteries [42].

7. **In electromyography** for detecting muscle fatigue [43], muscle activity [44] and the multichannel analysis of a long-term intramuscular signal [45].

II. In the systems of the analysis of two-dimensional information:

1. In mammography for enhancement of contrast [46], denoising [47], image compression [48], the localisation of microcalcified clusters [49], the detection of limits [50], segmentations [51] and the classifications of pathological tumours [52].

2. In echo cardio-graphic image for detection of heart wall borders [53], image compression [54], and the analysis of myocardial motion [55].

3. In functional magnetic-resonance tomography for the encoding images in order to decrease of a visualisation time [56], denoising (noise reduction) of scanned images [57], the research of brain functions [58], image compression [59].

4. In computer tomography for filtering projection noise [60], image reconstruction [61] in a local tomography where it is necessary to renew precisely only the local area on the image (at the same time a radiation dose considerably decreases) [62] and image compression [63].

5. In positrone emissive tomography for image reconstruction [64] and image denoising [65].

6. In angiography for 3-D image reconstruction [66], the compression of angiogram video sequences [67].

7. In colonoscopy for the detection of pathological tumors on the colour video image of the intestines [68].

8. In ultrasonic diagnostics for denoising [69], the edge enhancement of objects [70] and the compression of ultrasound images [71].

3. Conclusions

This review is not considered to be absolutely complete. Recently the limited quantity of the works devoted to some aspects of this field (See for example [72, 73]) have appeared in Ukraine. But they cannot change a situation in the state according to the world tendency of the development of information technologies for computer diagnostic systems.

The situation in Ukraine is quite different:

1. In domestic practice the analytical apparatus of biorthogonal basis and frames has not had the appropriate application to creating advanced information technologies.

2. The methods and means of mathematical morphology have not been reflected in the domestic scientific literature.

3. Wavelet-technologies are not used in domestic diagnostic systems. Separate research only underlines the scantiness of efforts.

These circumstances make impossible the achievement of a world scale of quality of computer diagnostics in Ukraine. We hope that this review will be taken into consideration by the researchers and developers of software and hardware for processing the diagnostic information. It also concerns profile chairs in the Ukrainian institutions of higher education training specialists in the development of diagnostic equipment. Only under such conditions Ukraine can compete with the countries which are successeful in the world scene of diagnostics.

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ІНФОРМАЦІЙНА ЕЛЕКТРОНІКА: ТЕХНОЛОГІЇ БІОМЕДИЧНОГО ОГЛЯДУ ОБРОБКИ СИГНАЛУ

Ю. Якименко, Л. Писаренко

Стаття присвячена дослідженню та застосуванню окремих перспективних методів обробки сигналів довільного фізичного (включно з біомедичним) походження. Проаналізовано умови використання ефективних інформаційних технологій в діагностичних системах України та відзначено невідповідність розвитку національних електронних систем та технологій обробки діагностичної інформації сучасним світовим тенденціям.

Yakymenko Yuriy academician of National Academy of Science of Ukraine, professor, DSc, vice-rector, Honoured Science and Technology Worker of Ukraine, State prize winner. motor, mathematical model.

Leonid Pysarenko – DSc, professor. Research interests: problems of modelling in electronics, including automited, designe of electronic equipment, data proccessing analysis by using stochastic information channals, the development of methods and means of probabilistic information system analysis.