Medical Computer System for Diagnosing the State of Human Vessels

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Abstract

In the work, the mathematical support of the medical computer system for diagnosing the condition of human vessels is developed, which is based on the method of wavelet processing in the Morlet basis. Algorithmic support was developed on the basis of mathematical support, which made it possible to develop software with a graphical user interface in the Matlab environment for a medical computer system. The developed system provides a study of the structural fluctuation of the pulse signal in the time space of observation of different scales according to diagnostic signs in the form of spectra of wavelet coefficients, which makes it possible to identify timely changes in human vessels.

Keywords

medical 1computer system, pulse signal, human vessels, method of wavelet processing, algorithmic support, software, Matlab.

1. Introduction

The development of a medical computer system, which is implemented using the photoplethysmographic method [1, 2, 3] for the task of diagnosing the condition of the vessels of the human system, is an urgent task. The system makes it possible to obtain diagnostic signs as indicators of the state of human vessels by registering the pulse signal (PS) and further processing it by means of mathematical, algorithmic and software.

Analysis of well-known medical computer systems for diagnosing the functional state of human vessels (Mobil-O-Graph, BPLab, PulseTrace 2 (USA), rteriograph 24, Oscar 2, BPro and others) found that they are limited in processing the pulse signal in order to obtain in addition to the assortment of diagnostic signs, the number of which is determined by the capabilities of the mathematical and algorithmic-software processing of the PS. Among the existing mathematical support of computer systems for diagnosing the functional state of human vessels, the following methods of PS processing are highlighted: quantitative

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method (S.V. Pavlov, M.V. Makhotniuk, B.B. Mlynko, M.E. Fryz) [4, 5], statistical method (Marchenko B., Mlynko B., Fryz M., Pastukh O.A.) [6, 7, 8], spectral method (Zudov O.M., Sharpan O.B., Danylevska V.G., Lutsuk O.V., Rybin O.I., Sharpan O.B., Yankovenko O.D., Allen J. Murray, etc.) [9-15], spectral-correlation method (Zudov O.M.) [10], the wavelet method with the Dobeshe basis function (N.V. Muzhitska, V.V. Hnilitskyi) [16], the synphase/component method (L.V. Khvostivska) [17, 18].

The design of computer diagnostic systems in medicine is impossible without sensors, which are very important [19-21], especially considering their stability at the stages of development, testing, and operation [22-25]. At the same time, the design of cyber-physical and computer medical systems for biomedical research [26, 27] with their numerical modeling [28] and the development of appropriate software systems [29] using neural network clustering technology [30] and computing methods [31-41] for medical image and biomedical signal processing is a modern and promising scientific area.

The indicated methods of PS processing in relation to wavelet processing do not provide research of structural fluctuation of PS in the time space of observation of different scales, which is necessary for timely detection of changes in human vessels. When searching for effective methods of PS processing, researchers did not use the full potential of wavelet processing, but limited themselves only to the Dobeshe basis function.

Therefore, the extension of new basis functions to wavelet processing of PS will ensure the development of a new effective algorithmic software for a new medical computer system for calculating new diagnostic information about the state of blood vessels, which will ensure their diagnostic level.

2. Hardware support of the medical computer system for diagnosing the state of human vessels

The hardware of the medical computer system for diagnosing the state of human vessels in the form of a computer photoplethysmograph (Fig. 1), which was developed by Liliia Khvostivska and Mykola Khvostivskyi at the Department of Biotechnical Systems of Ternopil Ivan Puluj National Technical University, was used for PS registration.

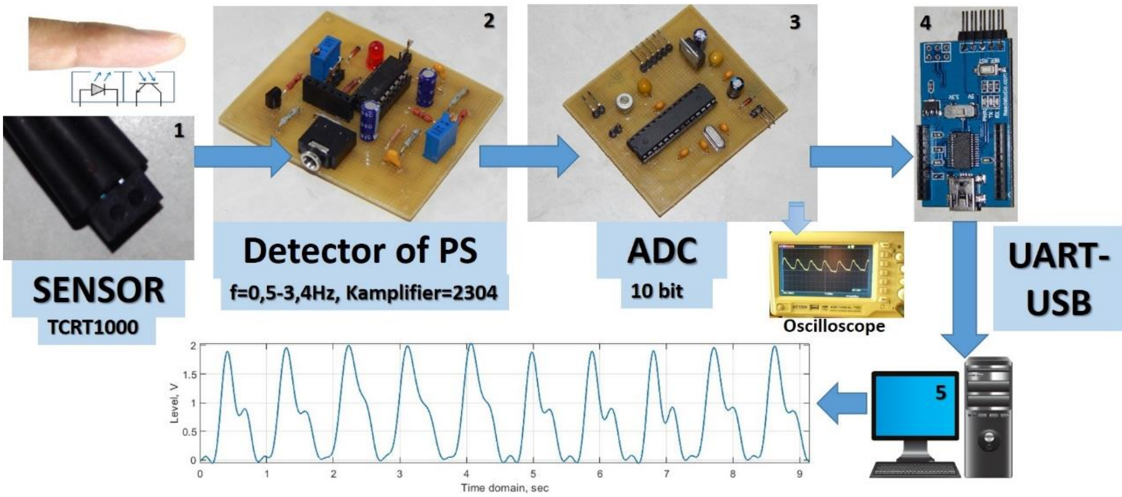
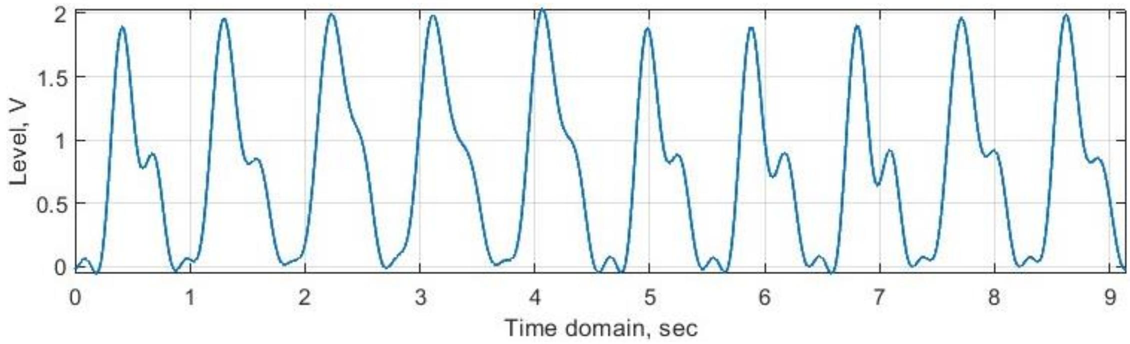
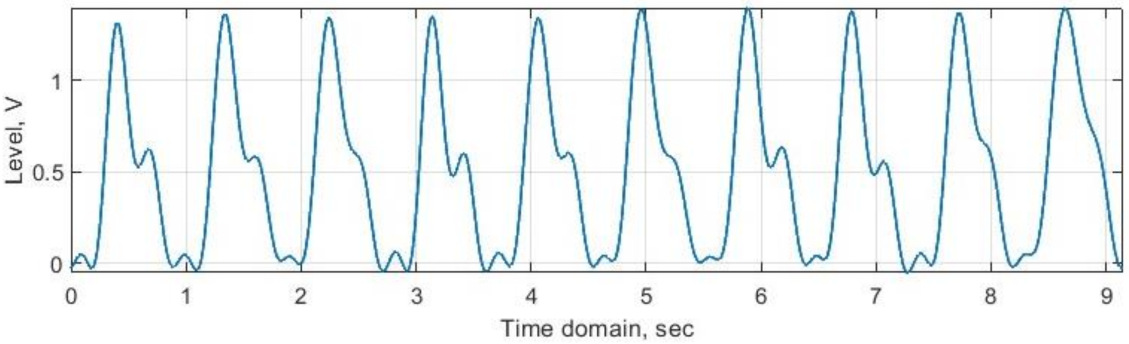


Figure 1: Hardware support of the medical computer system [42]

The optical sensor 1 TCRT1000, which is used as a PS sensor, has a structure that includes an LED as an infrared (IR) radiation source and a phototransistor as a receiver that receives infrared radiation reflected from the surface of blood vessels. The PS detector 2 is responsible for amplifying the low-amplitude PS to the necessary amplitude level for its further detection and ensures the matching of the detector 2 output with the ADC 3 input relative to impedance (resistance). ADC 3 performs the process of converting analog PS into digital format for further connecting the output of the previous unit to PC 5 via UART-USB 4. At the software level, PC 5 performs the process of processing data of the PS, including saving, processing, visualization and other operations.
The registered PS with the developed system layout and the implemented system are shown in Fig. 2.



(a)



(б)

Figure 2: Registered PS hardware part of the computer medical system (developers - Khvostivska L.V., Khvostivskyi M.O. [42]: a) normal state; b) pathology (change in stiffness)

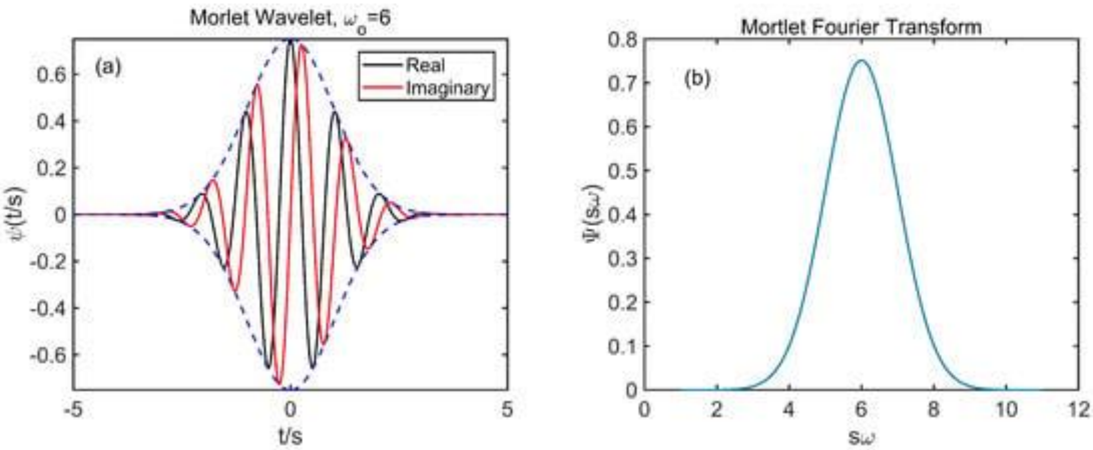
3. Mathematical support of the medical computer system for diagnosing the state of human vessels

Many biological and physical systems demonstrate rhythmic processes, in particular the PS [3, 31, 32]. The rhythmic temporal structure of PS embedded in a sequence of numerical data can be extracted and quantified using the Fourier transform (FT) or other spectral processing methods, including the wavelet transform. Wavelet transform (Wavelet Transform), which has a high resolution in both the frequency and time domains. It not only indicates which frequencies are present in the signal, but also at what time these frequencies occurred. This is achieved by working with different scales in accordance with the expression [43]:

$$W(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} s(t)\, \psi\left(\frac{t-b}{a}\right) dt, \tag{1}$$

where $\psi\left(\frac{t-b}{a}\right)$ - wavelet processing kernel (basis); a – scale factor, b – time shift.

Most PS data usually consists of periodic bursts of sinusoidal oscillations, it is not surprising that the most common basic wavelet is the Morlet wavelet [44, 45], which consists of a complex plane wave modulated by a Gaussian (Fig. 3) (the Morlet wavelet is defined as a sinusoid, tapered to Gauss).



(a) (b)

Figure 3: (a) Morlet wavelet in the time domain: the real part is marked in blue and the imaginary part in red. (b) Morlet wavelet in the frequency domain [46]

The complex form of the Morlet basis is represented as a complex exponent modulated by a Gaussian function:

$$\psi(t,a,b) = e^{i\omega\frac{t-b}{a}} e^{-\frac{1}{2}\left(\frac{t-b}{a}\right)^2} \tag{2}$$

where ω – base frequency; a – scale factor; b – time shift.

The choice of wavelet width is a combination of PS processing considerations and theoretical/speculative considerations of the system with which the PS is registered. This parameter is therefore important for the analysis of time-frequency data, and yet is often chosen and reported in a way that obscures the assumptions underlying the processing of the PS data.

4. Algorithmic support of the medical computer system for diagnosing the state of human vessels

On the basis of wavelet processing in the Morlet basis, the algorithmic support for PS processing is implemented, which is shown in Fig. 4.
According to the implemented algorithm, which is shown in Fig. 4, the following stages are carried out: entering the values of the scale coefficients, time shift, interval time as a sequence, calculation of the frequency of the base ω and f-th of the base Morlet, wavelet coefficients $C(a,b)$ depending on a, b, t when applying cycle, and then switching to the frequency representation using the Fourier transform function $W(f,a,b)$.

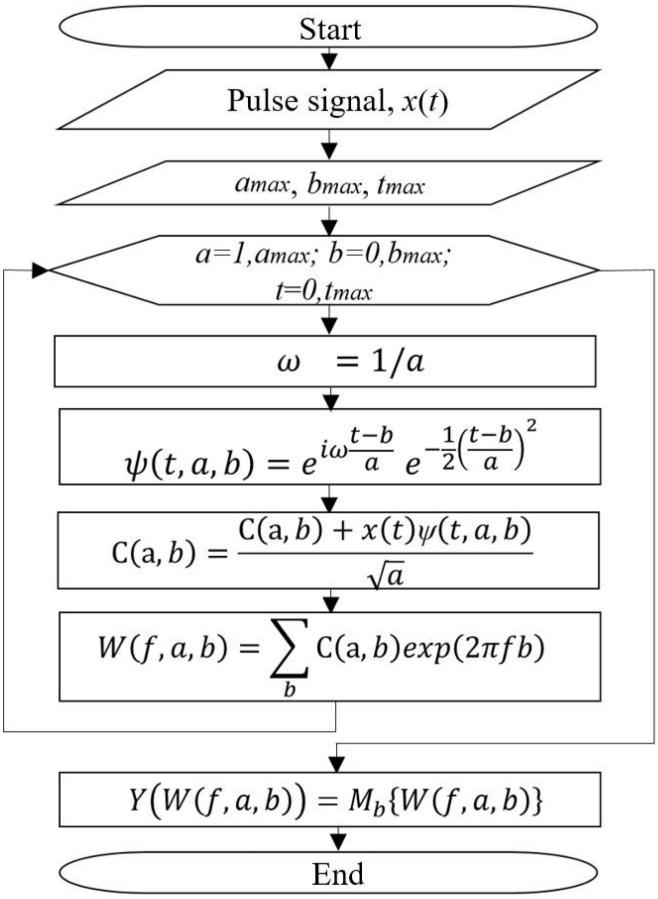


Figure 4: Algorithmic support of wavelet processing (Morlet basis) of the PS

The implemented algorithm provides processing of the PS signal as part of the computer system when using wavelets, which allows you to study the time-frequency fluctuations of the signal in a three-dimensional projection. This provides an opportunity to monitor all variations in the structural units of vessels, indicating min or max disturbances in their functioning.
Algorithmic support of the computer system for diagnosing the state of human vessels is shown in Fig. 5.

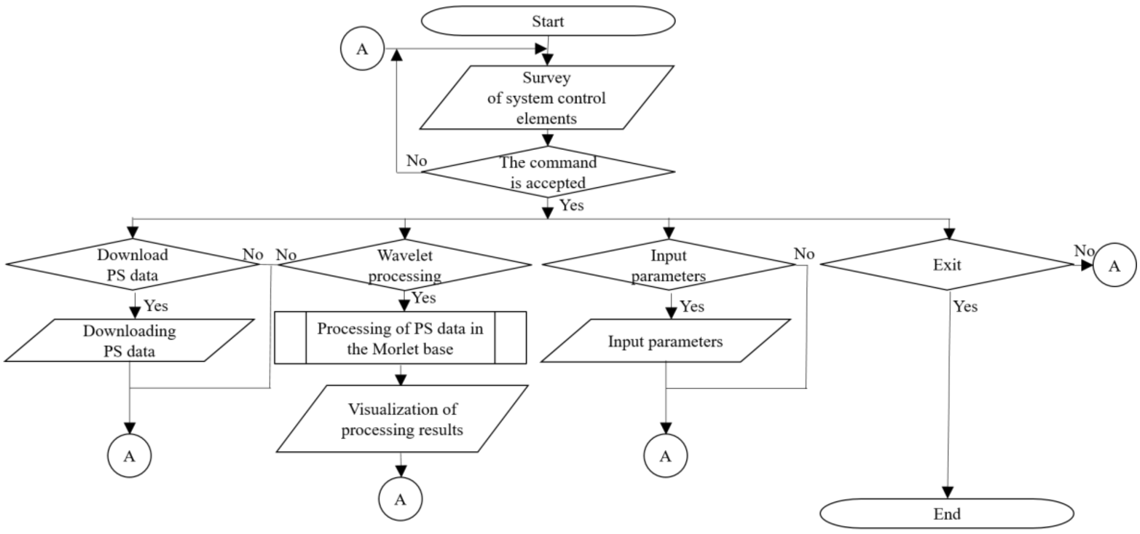
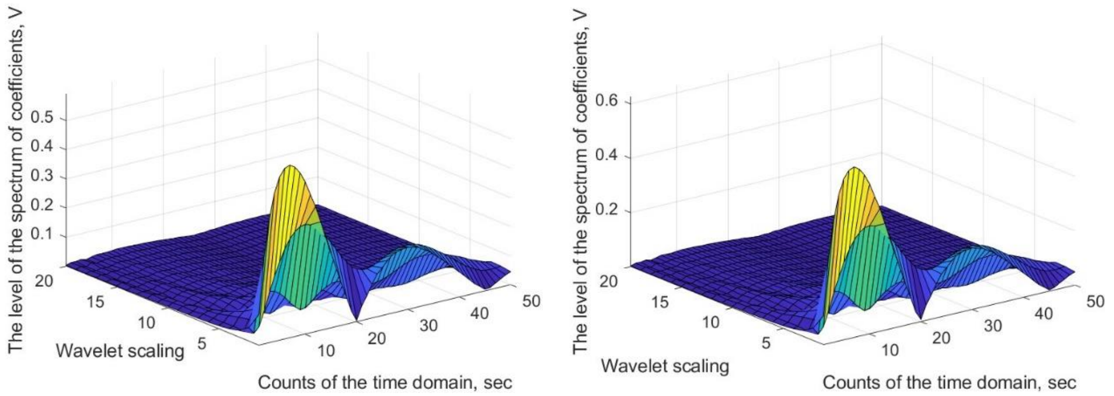


Figure 5: Algorithmic support for the functioning of the computer medical system for diagnosing the state of human vessels

This system, in accordance with the developed algorithmic support (Fig. 4), provides for the following operations: loading of PS data, input of processing parameters, wavelet processing in the Morlet basis, data visualization and exit from the system.

5. Software of the medical computer system for diagnosing the condition of human vessels and the results of its work

The Matlab environment was used to develop the wavelet processing software based on the developed algorithm (Fig. 5). The result of the software is shown in Fig. 6 in the form of a 3D representation as a "time-scale-spectrum" dependence.



(a) (b)

Figure 6: Spectral 3D presentation of wavelet PS coefficients of patients in a normal state (a) and pathology (b)

Spectral data (Fig. 6), which are presented in 3D, are visually identical, that is, full invariance is preserved, but numerically evaluating the level of deviations between them is a complicated process. Therefore, the well-known works of the scientist of the Department of Biotechnical Signals, in particular Khvostivskyi M.O., the criterion for averaging spectra by time shifts in accordance with the expression:

$$\hat{Y}(a,b) = M_b\{W(a,b)\}. \quad (3)$$

The average value of spectral 3D views is shown in Fig. 7.

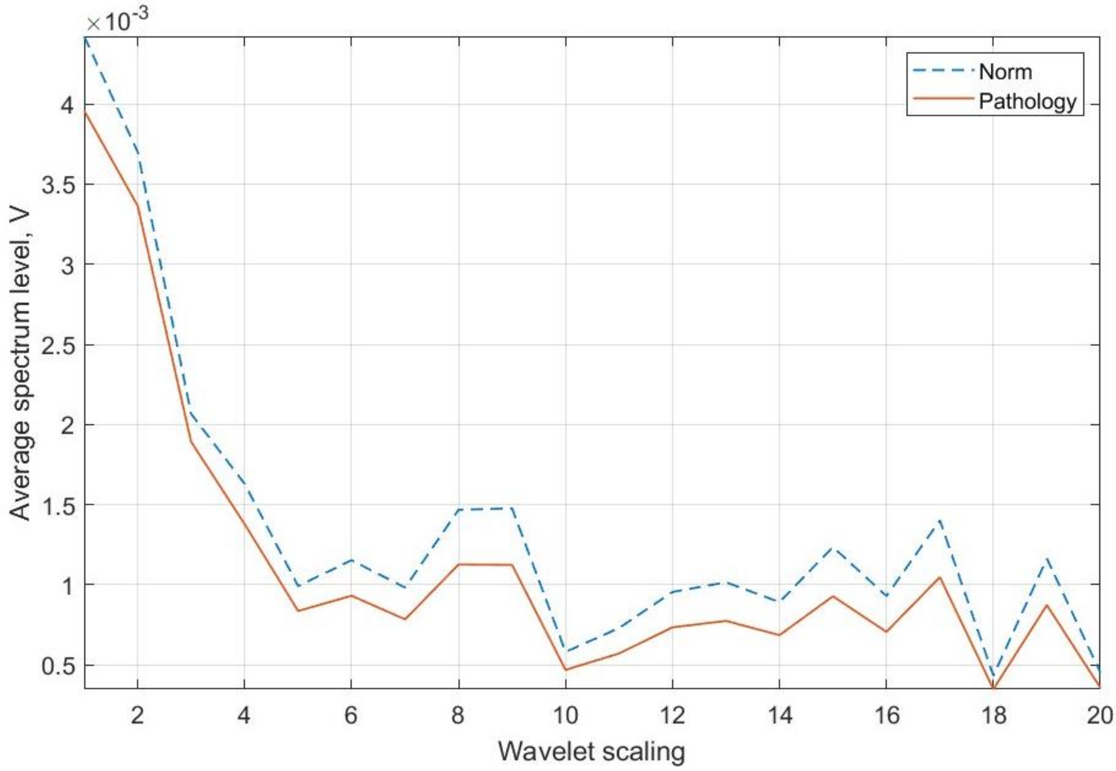


Figure 7: Averaged 3D data of spectrally presented wavelet coefficients

According to the data in Fig. 7, it can be seen that the diagnostic parameters as a set of coefficients are invariant, that is, localized for different states of vessels on the same scales. Spectra by level for the state of pathology (increased stiffness of blood vessels) in relation to the norm are lowered, which clearly indicates the presence of a pathological state that occurs in the vessels.

The GUIDE Matlab module was used to develop software for a computer system with a graphical user interface for automated processing of PS based on algorithmic support (Fig. 5).

The developed interface of the system and the result of its work are shown in Fig. 8.

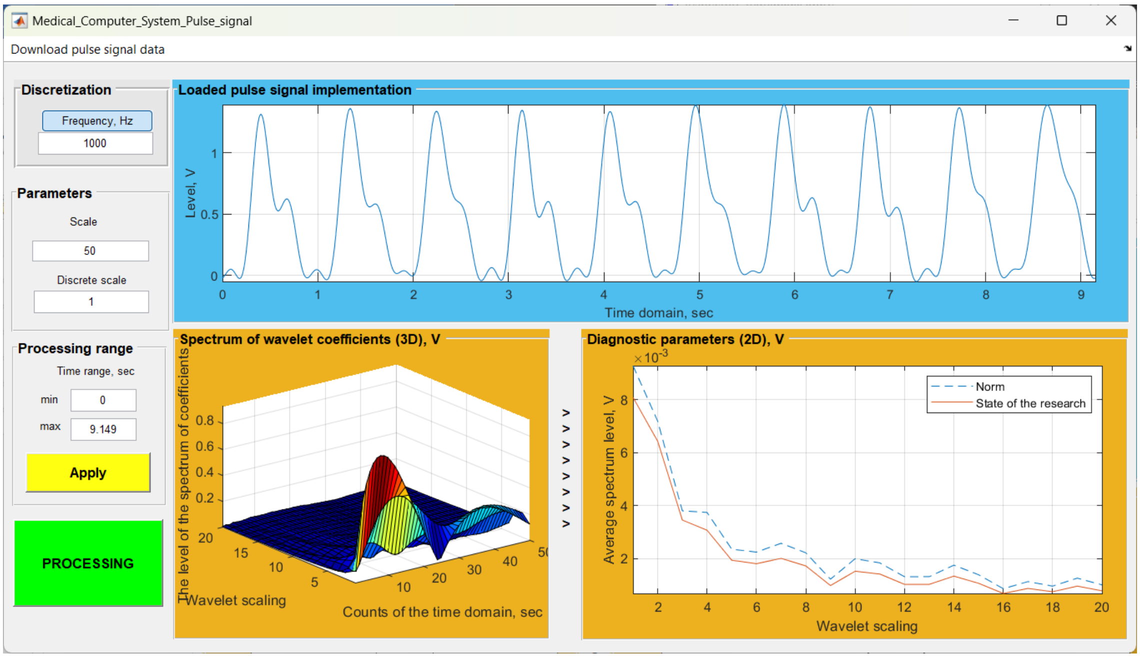


Figure 8: The result of the developed medical computer system, in particular its software

The result is developed software that allows the user (doctor) to automate the process for studying the state of blood vessels. The displayed results clearly reflect the changes between different states, particularly normal and pathological. Similarity of the structure (invariance) is inherent to both states, but a change in the level of the spectra is noted. Such a change indicates the manifestation of a pathological state of blood vessels.
Therefore, the proposed diagnostic parameters make it possible to monitor timely changes in the functioning of blood vessels and thereby expand the diagnostic level (+1 diagnostic feature) of medical computer systems for diagnosing the state of human blood vessels.

6. Conclusions

Mathematical support, algorithmic support and software for processing the pulse signal in the core with the method of wavelet processing in the Morlet basis were developed for the calculation of new diagnostic information in the form of a spectral representation of wavelet coefficients, which ensured the development of a medical computer system for diagnosing the state of human vessels and expanding the diagnostic level of existing systems
Matlab tools and its Guide module were used in the development of the system software.
The operation of the medical computer system was investigated and it was established that the system functions correctly and clearly reflects changes in the state of human vessels by 3D and 2D (3D averaging) realizations of wavelet coefficient spectra (new diagnostic parameters).

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