On the possibility of analysis using the wavelet transform of the pulse waveform from the bloodstream

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Abstract. A method has been developed using wavelet transform to describe the dynamics of the pulse wave shape during the diagnosis of human health. The pulse wave signal, in contrast to the previously discussed diagnostics, is considered an unsteady signal, in which there may be no periodicity. We found that this method is useful for diagnosing the properties of arterial vessels of patients with coronary heart disease, arterial hypertension and other diseases. Pulse wave research results are presented.

1. Introduction

The development of fast and reliable methods for express control of the state of condensed matter is one of the urgent problems of physics [1-8]. The most significant difficulties arise when monitoring the state of current media in pipelines [9-14]. Various devices and sensors have been developed to solve these problems [10-17]. In cases of restriction of access to the pipeline, non-contact methods using the phenomena of nuclear magnetic resonance and optical radiation are used to monitor the state of the medium [16-27]. The study of the parameters of blood flow in veins and blood vessels is one of the most challenging tasks since blood contains a lot of information about the work of various human organs [28-32]. Deciphering this information gives a large amount of new knowledge.

The blood movement in the vessels is based on the alternation between two processes: relaxation (diastole) and contraction (systole) of the ventricles of the heart. During diastole, the ventricles are filled with blood, and during systole of the ventricular myocardium, blood is expelled from the heart to the aorta and pulmonary artery under pressure [18-20, 29, 32-35]. Blood enters the aorta, and it expands until it stops the flow of blood does not stop. The rhythmic contraction of the myocardium causes a contraction of the vascular wall, and the pulse wave propagates from the initial part of the aorta to the arterioles and capillaries. There are several methods used to register a pulse wave. Pulse oximetry (registration of a pulse wave using scattered or reflected laser radiation on blood vessels or veins), unlike others, has gained more extensive application both in clinical diagnostics and for the personal use of various groups of people [26, 32-36].

For a quantitative analysis in a pulse wave using the method of "one hit". With its use, the position of the maxima and minima on the timeline and their characteristic amplitudes are determined. The shape of the pulse wave depends on the elasticity of the vessel wall, pulse rate, features of the heart
and several factors that may be associated with a disease of human organs [35-37]. The description of the pulse wave shape is often performed only for stationary processes using the Fourier transform. The experiments showed that the Fourier methods for non-stationary processes are challenging to apply. Therefore, we propose to use an algorithm based on the wavelet transform to analyse the pulse wave shape [36, 37]. It allows developing a system of quantitative parameters for diagnosing the state of arterial vessels and the work of the human heart.

2. Pulse waveform analysis technique

Figure 1 shows pulse waves of two people with different health conditions as an example.

![Figure 1 (a, b). The pulse waveform of men: (a) at the age of 22 years; (b) at the age of 24 years.](image)

Even in the case of a satisfactory health state, the formation of a pulse wave is an unsteady process. Therefore, to describe the shape of the pulse wave, the signal is proposed to be expanded into basic functions using the operation of compression/extension and shift of some oscillating and location function, which is called the mother wavelet. As a mother wavelet, we propose to use the Morlet function [36, 37]. This function has a zero-mean value. For a quantitative analysis of an unsteady pulse wave signal, we use the integral wavelet transform:

\[ V(x, t) = \nu \int_{-\infty}^{+\infty} z(t') \varphi^*(\nu(t' - t)) \, dt' \quad (1) \]

where \( \varphi(x) \) – is the mother wavelet.

Expression (1) represents the initial one-dimensional pulse wave signal \( z(t) \) in the time-frequency plane. It should also be noted that the mother wavelet \( \varphi(x) \) must be well localized at \( x = 0 \), have a unit norm, its average value in the whole interval is zero. Therefore, its following form is proposed:

\[ \varphi(x) = \frac{\exp\left(-\frac{x^2}{2}\right)(\exp(-i\Omega_0 x) - \exp\left(-\frac{\Omega_0^2}{2}\right))}{\sqrt{\pi} \left(1-2\exp\left(-\frac{\Omega_0}{4}\right)\right)^{\frac{1}{4}}} \quad (2) \]

For values of \( \Omega_0 = 2\pi \), the maximum of \( |V(x, t)|^2 \) for frequency \( f_1 \) corresponds to the following relation \( f_1 = v \). It allows us to use (2) to study unsteady signals that change over time.

3. Results and discussion

In many cases, when conducting research, an arbitrary non-stationary signal \( Z(t) \) can be represented as a superposition of the simple non-stationary signals:
where $b_L$ is the signal amplitude, $\tau_L$ is the signal localization width in time, $f_L$ is the signal localization centre in frequency, $t_L$ is the signal localization centre in time, and $\alpha_L$ is the phase.

It can be shown using the principle of superposition that the continuous wavelet transform (CWT) of the total unsteady signal $Z(t)$ is the sum of the CWT of unsteady elementary signals:

$$V(v, t) = \sum_{L=1}^{N} V_L(v, t)$$

Figure 2 shows sections of a given surface $V(v, t)$ for fixed variables. The first section of the surface is made at a fixed time $V(v, t = t_L)$. The second section of the surface is made at a fixed frequency $V(v = f_L, t)$. Graphs 1, 2, 3, 4 correspond to the values of $m$: 1, 3, 5, 7.

The dependency analysis in Figure 2 shows that as the parameter $m$ increases, the peak width in frequency decreases significantly, and the peak width in time increases slightly. The time localization region is preserved for parameters $m$ in the interval $1 < m < 7$. This analysis, in some cases, after processing a pulse wave signal using a wavelet transform, make it possible to establish the presence of an artifact in information about human health.

4. Conclusion

Using the adaptive Morlet wavelet allows obtaining a more accurate diagnosis of the frequency and time localization of the signal under study by changing the parameter $m$ in calculating $V(x, t)$.

The use of wavelet transforms when processing a pulse wave allows getting additional information about the process of restoring the body after a load. And the reliability of the results of diagnosing a person’s health condition using a pulse oximeter increases.
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