The features of continuous wavelet transform for physiological pressure signal

Boronoyev V.V., Garmaev B. Z., Lebedintseva I.V.
Laboratory of Pulse Diagnostics, Department of Physical Problems, Buryat Scientific Center, RAS (Siberian Branch), Sakhayanovoi st. 6, Ulan-Ude, Russia, 670047

ABSTRACT

The paper shows the possibility of continuous wavelet transform application for the analysis of pulse model signals. It has been found that wavelet analysis is capable of defining local characteristics of a signal and investigating any changes in the spectral distribution of a pulse signal. The wavelet spectra of pulse signals of healthy people and of people with functional disorders have been investigated. It has been shown that the shape of pulse signals of people with functional disorders is changing, which brings about change in the wavelet spectra. The paper describes a new wavelet-based detection method for physiologic pressure signal components.

Keywords: wavelet transform, physiological pressure signal

1. INTRODUCTION

The pressure signal of the radial artery provides information of different physiological processes going on in the organism. Obtaining this information requires detailed analysis of the pressure signal components. Thus, for temporal analysis of the heart activity, based on computing the lengths of the phases of the heart cycle and the analysis of their temporal correlations, correct determination of the informative points of a pressure signal is required.

The fact is that pressure signals are non-stationary because its frequency structure and basic characteristics are time varying. That's why a number of traditional methods of analysis (Fourier transform, autocorrelation analysis, time-amplitude analysis) are not sufficiently effective for revealing different local characteristics and fluctuations of a pressure signal.

Nowadays, a new method of wavelet transform is used for the analysis of non-stationary signals. Wavelet transform is applied to the detail analysis of non-stationary signals that have complicated structures like pressure waves. This is especially important for detecting the characteristics points in low amplitude segments; the definition of their positions has principle importance for the accuracy of the diagnosis.

The aim of this work is the evaluation of the possibility and expediency of using the wavelet-analysis method for automating the process of detecting the disorders in the regulating systems of an organism and for signal components detection.

2. CONTINUOUS WAVELET TRANSFORM (CWT)

The wavelet transform decomposes a signal into a set of basic functions called wavelets. These are obtained from a single prototype wavelet, called a mother wavelet, by dilatations and by shifts.

Wavelets are functions that satisfy certain mathematical requirements: this function must have zero mean and be localized in both time and frequency range.

Different versions of wavelet functions are obtained from the basic wavelet by translation and dilation as follows:

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$$\psi_{a,b}(t) = \psi\left(\frac{t}{a} - \frac{b}{a}\right) = \psi\left(\frac{t-b}{a}\right)$$

where a<>0 is the scale and b – is the position (or time)

A large value of the scale a stretches the basic wavelet function and makes the analysis of low-frequency components of the signal possible. A small value of a gives a contracted version of the basic wavelet and then makes the analysis of high-frequency components possible. Thus, the continuous wavelet transform is well suited for localizing frequency and for localizing time

Wavelet transform has an infinite set of possible basic functions and their choice depends on the current task. Different mother wavelets give rise to different classes of wavelets; hence, the behavior of the 'decomposed' signal could be quite different. The mother wavelet should be chosen carefully, so that it exhibits good localization in both the frequency and spatial domains.

The continuous wavelet transform is expressed as [1,2]

$$W(a,b) = \langle f, \psi_{a,b} \rangle = \int_{-\infty}^{\infty} a^{-1/2} \, \overline{\psi\left(a^{-1}(t-b)\right)} \, f(t)dt$$

where the (̄) indicates the complex conjugate and $f(t) \in L^2(R)$.

Wavelet transform gives 3D representation of a signal as amplitude, frequency and time. Usually, for the wavelet transform representation, the filled contour plot is used; the x axis represents time, and the y axis indicates the wavelet scale, the colors indicate the values of the wavelet amplitudes. Besides, the y axis can be logarithmic.

3. USING THIS WAVELET ANALYSIS OF MODEL SIGNALS

The basic features of this method are shown in model pressure signals. Let's consider a sinusoid that has frequency of 1 Hz, break point at t=5 s and jump at t=8 s (fig. 1a) and its wavelet spectrum (fig. 1b). Large values of wavelet coefficients correspond to the extremums of a signal; these are the dark areas in wavelet-spectrum (fig. 1b). Low values of wavelet coefficients (the light areas) correspond to the zeros of a signal.

The vertical lines (the so called influence cones – dark conical patterns, which are wide for large durations (low wavelet pseudofrequencies) and become progressively narrower for smaller durations (high wavelet pseudofrequencies) in the wavelet spectrum (fig. 2b) correspond to the artifacts and break points. These cones uniformly converge to the t=5 s and t=8 s for high wavelet pseudofrequency. The sharper the feature is expressed, the more exactly it is allocated in the wavelet-spectrums and the higher the values of wavelet coefficients are. A horizontal stripe of "ellipses" in the wavelet-spectrum, which corresponds to the alternation of the extremums and zeros in the signal, indicates to the wave period (1 Hz frequency) in the sinusoid. Certain complications of the wavelet-spectrum on the edges are edge effect of a time-limited signal.

Wavelet transform is capable of revealing the changes in the spectral structure of a signal, which is shown in model pressure signals that consist of three harmonics (frequencies 1, 2, 13 Hz) which change their periods. In the wavelet spectrum of the model signal (fig. 1c) the horizontal stripes corresponding to the frequencies of the harmonics of the signal, change their position depending on the change of the period. For this signal, the Fourier spectrum would contain three harmonics without giving any information of their changes (evolution).

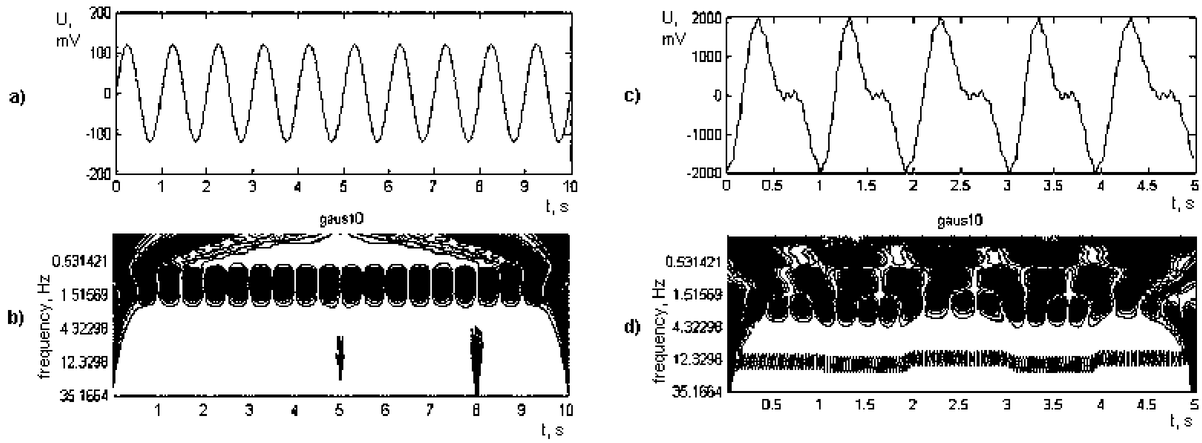

Fig.1. a – the sinusoid that has the frequency of 1 Hz, break point at *t*=5 s and jump at *t*=8 s; b –wavelet spectrum of the sinusoid; c – model pressure signal; d – its wavelet spectrum.

Thus, the wavelet-analysis gives new opportunities to the detailed analysis of non-stationary signals, such as pressure signal, for which the application of Fourier transform is not very effective. It allows:

- to detect the local features of pressure signals, i.e. characteristic points, artifacts and fluctuations, including those in the low amplitude segments. Large values of wavelet coefficients are close to the local features of a pressure signal; and small values are found in the places where the function is locally smooth.
- to analyze the changes in the spectral structure of pressure signals and their characteristics that are not reflected in Fourier -spectrums.

4. EXAMPLES OF CWT'S APPLICATION FOR PRESSURE SIGNAL

Continuous wavelet transform has been used for the analysis of pressure signals of healthy people and people with functional disorders and its wavelet spectrums have been compared. The results of a continuous wavelet-transform of pressure signals of two patients with different states of health are shown in fig. 2.

While comparing the results of wavelet transforms of two patients, we see that additional local features (frequencies from 6 to 23 Hz) in the wavelet spectrum of the patient with functional disorders are visible. But the wavelet spectrum of the pressure signal of the healthy patient does not show any local features in this range.

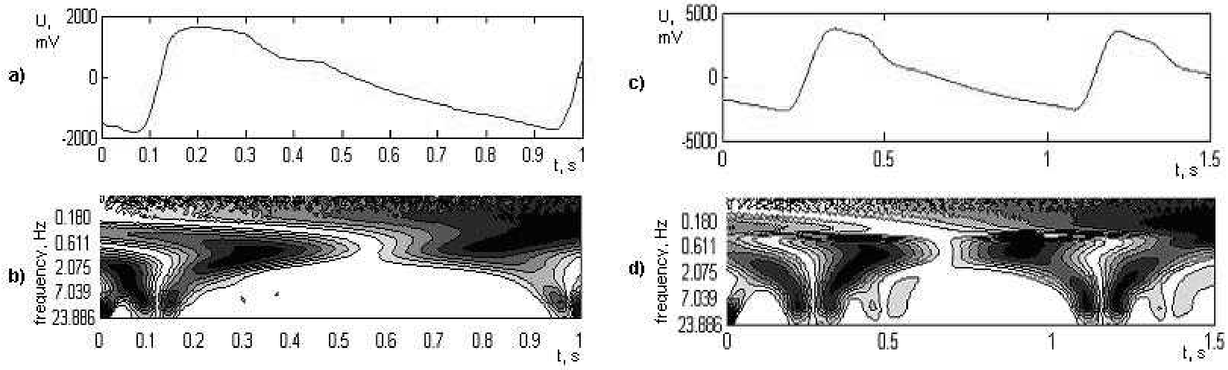

Fig.2. a – the pressure signal of healthy people; b – its wavelet-spectrum; c - the pressure signal of people with functional disorders; d - its wavelet-spectrum.

For more detailed analysis of the low-frequency structure of a signal (in the range from 0,01 Hz and higher) we are analyzing long recordings of pulse waves (100 seconds). The results of the wavelet transforms of these pressure signals are shown in fig. 3.

In the wavelet spectrum of the healthy patient, the stripe, corresponding to the basic frequency of the signal, has high variability (fig.3b). In the wavelet spectrum of the patient with functional disorders (fig. 3e), the stripe, corresponding to the basic frequency of the signal, is practically even, which indicates the decreasing variability of the rhythm of the heart beats. Additional local features appear in the wavelet spectrum of the patient with functional disorders (fig. 3e) in the frequency about 0,022 Hz. These periodic local features in the wavelet spectrum of the sick patient indicate an additional harmonic, which is absent in the wavelet spectrum of the healthy person (fig.3b). However, these local features, as well as the harmonic, disappear in t=50 s.

A change in the frequency content of the signal in the range from 0,02 to 1 Hz can be observed in the global wavelet spectrum (fig.3c,f).

Thus, the wavelet spectrums of patients with functional disorders differ from the wavelet spectrums of healthy patients. In the wavelet spectrums of people with functional disorders, the frequency structure in the low frequency range changes and additional local features in the range from 8 to 23 Hz appear.

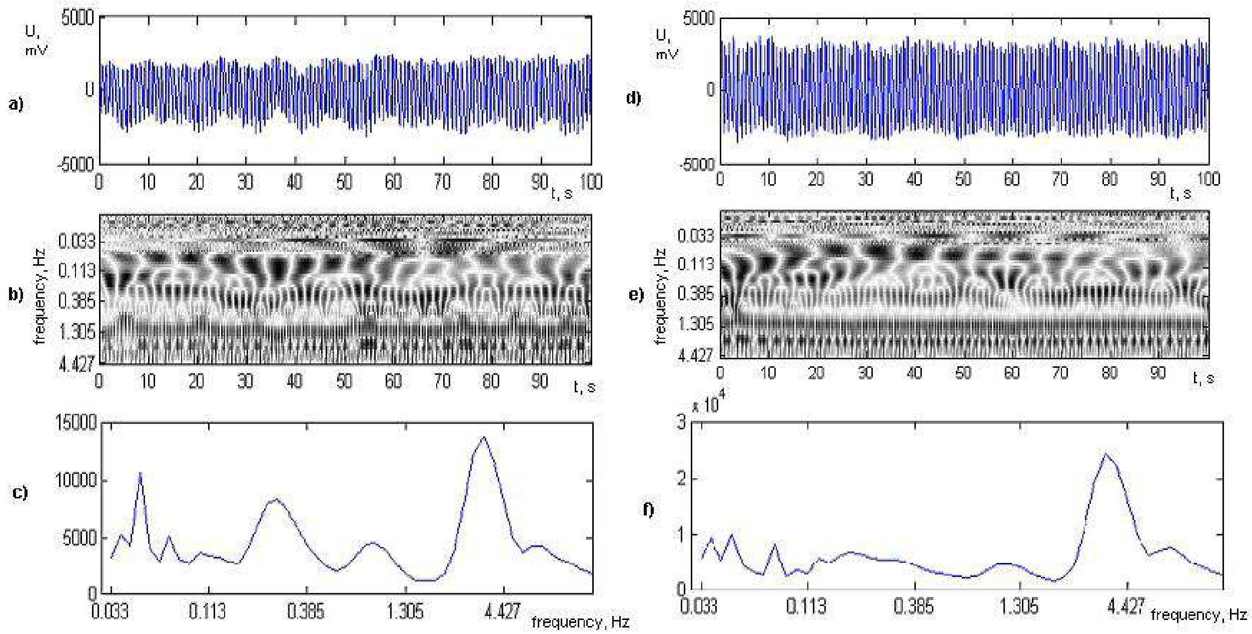

Fig. 3. a – the pressure signal of healthy people (100 sec); b –its wavelet spectrum; c – its global wavelet spectrum; d - the pressure signal of people with functional disorders (100 s); e - its wavelet-spectrum; f – its global wavelet spectrum.

The appearances of additional local features on the wavelet spectrum are connected with changes of pressure signal shape, which influences on the pressure signal components. Pressure signal components detection is important problem of evaluation of people's functional condition.

5. CONTINUOUS WAVELET TRANSFORM FOR DETECTION OF PRESSURE SIGNAL COMPONENTS

For detecting pressure signal components, we suggest using a continuous wavelet transform for a discrete pressure signal [1]:

$$W(a,b) = \frac{1}{\sqrt{a}} \sum_{k} f(k) \int_{k}^{k+1} \psi\left(\frac{b-t}{a}\right) dt$$

where a is scale coefficient, b is shift parameter, k is sampling increment, f(k) is a discrete pressure signal. We are using the Haar wavelet, which is an ortonormal wavelet with a compact support [3].

$$\psi(t) = \begin{cases} 1, & 0 \le t < 0.5 \\ -1, & -0.5 \le t < 0 \\ 0, & otherwise \end{cases}$$

The essence of this method is the wavelet transform of the signal under analysis (fig. 4a) and we get a picture of absolute values of the wavelet coefficients (wavelet spectrum) shown in fig. 4b where zero values of the wavelet coefficients are white marked and clearly seen. The next stage of the algorithm of signal components detection is the selection of the fixed scale (frequency) in the picture of the wavelet coefficients taking into account the characteristic scale that makes it possible to detect the required signal components. In fig. 4b the wavelet coefficients in the selected frequency are labeled by line 1. The value of the frequency has been selected taking into account the minimization of the noise influence on the accuracy of the signal components detection. On the final stage of the signal components detection, we detect the zero values of the wavelet coefficients (the white areas of the wavelet coefficients) on line 1, which correspond to the model signal components, as it is shown in fig. 4b.

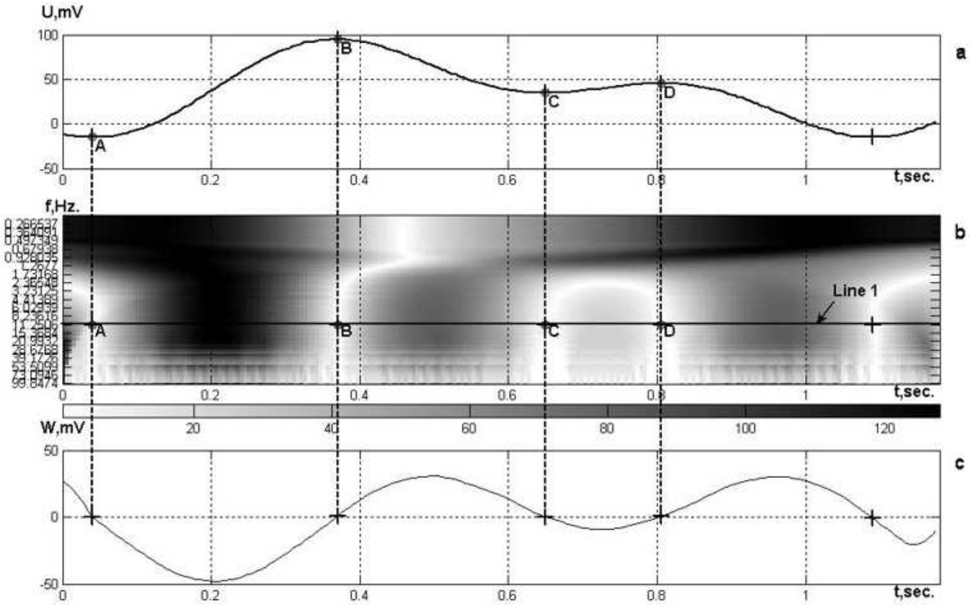

Fig. 4. a - model pulse wave; it's components (A,B,C,D); b - absolute wavelet coefficients; c - wavelet coefficients on selected scale (frequency).

It is shown that this method is very simple to use for pressure signal components detection and can have many applications.

6. CONCLUSIONS

The analysis of model pulse signals has shown that wavelet analysis is capable of revealing any changes in the spectral distribution of a pressure signal and defining local characteristics of a signal such as artifacts and break points. This method opens new opportunities in detail analysis of arterial pressure signal.

The analysis of the pressure signals of healthy people and people who have function disorders has shown that the local structure of the wavelet-spectrum of a pressure signal has definite changed in cases of disorders of an organism; the redistribution in the low frequency range of the wavelet spectrums take place. Also we represented novel wavelet-based method of pressure signal components detection.

Wavelet transform applied for the analysis of pressure signals is a promising method of digital processing. This method can be used for revealing and formalizing the signs of functional disorders of an organism. Wavelet-based detection method can be used to detect the beat-to-beat of pressure signals and the pressure signal components.

REFERENCES

1. I.Daubechies. ``Ten lectures on wavelets". SIAM, Philadelphia, 1992.
2. Y. Meyer. ``Wavelets: Algorithms and Applications". SIAM, Philadelphia, 1993.
3. Stankovic R.S., Falkowski B.J. The Haar wavelet transform: its status and achievements, Computers and Electrical Eng. 29,pp. 25-44, 2003.