Processing of the ECG orthogonal band-pass filter with the subsequent transfer in the phase plane

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Abstract. One of the methods of diagnosis and recognition of cardiovascular diseases is electrocardiography. The current state of diagnosis of cardiovascular diseases requires the development of new approaches to the analysis of electrocardiograms, there is a need to create new algorithms for processing information received from patients as a result of ECG removal. In this paper, it is proposed to use a band-pass orthogonal digital filter based on the Morlet wavelet function for processing electrocardiograms, which is not sensitive to the constant displacement of the input signal, does not have the Gibbs effect, which provides a better level of suppression in the barrier band obtained using the Fourier transform, followed by its transfer to the phase plane. The phase plane has found application in medicine for increase of reliability of the analysis and interpretation of an electrocardiogram for the purpose of increase of informativeness of cardiograms.

1. Introduction
In the structure of mortality in many countries, diseases of the circulatory system are in the lead. According to estimates by the World Health Organization, in 2016, 17.9 million people died of a circulatory system disease, which accounted for 31% of all deaths in the world.

One of the most common methods for the diagnosis and recognition of cardiovascular diseases is electrocardiography. An electrocardiogram is a component of the surface potentials, due to the electrical activity of the heart [1]. The remaining components of the potentials are considered interference. The cause of interference can be the electrical activity of the tissues through which the impulse is conducted, the resistance of the tissues, especially of the skin, as well as the resistance at the input of the amplifier. The theory of detecting the features of a signal and estimating its parameters is well developed [2, 3], but direct application of a number of classical solutions to the study of bioelectric signals is difficult, and often impossible.

Unfortunately, even regular observation by medical specialists does not always solve the problem of preserving health and life. So, there are cases when athletes died from a heart attack during training [4], who had been quite often examined by doctors before. It can be assumed that in pursuit of the goal of breaking another record, an athlete may for a short time exceed the permissible level of load, thereby causing fleeting fatal pathological changes in the cardiovascular system. Since such violations can occur...
suddenly and quickly lead to death, they are almost impossible to identify even with daily check-ups by a doctor.

These arguments dictate the need to create new algorithms for processing information obtained from patients as a result of ECG removal, in order to increase its information content.

In this paper, it is proposed to process the ECG signal with a digital filter obtained using the direct synthesis method, taking into account quantization effects by level and time, followed by transfer of the ECG to the phase plane [5]. At the same time, it is proposed to use a filter based on the Morlet wavelet function as a developed filter. The advantages of this filter are that it is not sensitive to a constant offset of the input signal, do not have the Gibbs effect, which provides a better level of suppression in the obstacle band than the filter obtained using the Fourier transform [2].

2. Orthogonal filter designing

Figure 1 shows the frequency response of a band-pass filter.

![Figure 1. Magnitude response of band-pass filter.](image)

To construct a bandpass filter, it is possible to use the wavelet transform [6]. In this case, the bandpass filter can be obtained by directly summing the Morlet wavelet functions with the required spectral characteristics, for this it is necessary to establish a relationship between its characteristics and the Morlet wavelet function [7]:

- $\Delta f$ bandwidth of the wavelet filter

$$\Delta f = 2f_0 \sqrt{\frac{2 \ln 2}{k}}$$  \hspace{1cm} (1)

where $f_0$ is the center frequency of the wavelet function, $k$ is the attenuation coefficient of the wavelet function.

- $Q$-factor of the Morlet wavelet function:

$$Q = \frac{\sqrt{k}}{2\sqrt{2\ln 2}}$$  \hspace{1cm} (2)

As can be seen from expression (2), the quality factor of the Morlet wavelet function is determined only by its attenuation coefficient. Therefore, when constructing a filter, it is necessary to take into account that as the frequency decreases, the bandwidth will decrease. However, by dividing the required bandwidth of the synthesized filter, we obtain an approximate number of wavelet functions that will make up the band-pass filter.

- attenuation coefficient of the Morle wavelet function, which depends on the boundaries of
integration [8]. The boundaries of integration and the frequency ratio also determine the order of the FIR filter:

$$k = 4 \cdot \frac{\Delta f_c^2}{(\Delta f_c - \Delta f)^2} \cdot \ln \Delta W_c.$$  \hspace{1cm} (3)

When carrying out the calculation, it is necessary to know that the maximum suppression in the obstacle band depends on the bit width \(n\) of the sample data stream arriving at the input of the filter.

$$\Delta W_{c_{\max}} = \sqrt{3} \cdot 2^{-n/2}.$$  \hspace{1cm} (4)

Expression (4) determines the maximum allowable value that can be taken to calculate the band-pass filter.

Figure 2 presents the frequency response of the bandpass filter, obtained by summing the wavelet functions with given characteristics.

![Frequency response of band-pass filter](image)

**Figure 2.** Frequency response of band-pass filter, obtained by summing the wavelet functions.

The constructed filter ‘inherits’ all the main features of the Morlet wavelet function, namely: the absence of the Gibbs effect and insensitivity to the presence of a constant bias in the signal.

3. **ECG translation into phase plane**

The following are the results of filtering an electrocardiogram developed by an orthogonal bandpass filter. Figure 3 shows the original cardiogram and its filtering by an orthogonal bandpass filter.
Figure 3. Cardiogram and the result of its filtration with an orthogonal bandpass filter: 1-source signal; 2-filtering with a real filter; 3-filtering imaginary filter.

The imaginary filter provides a shift of all frequencies included in the filter band by $90^\circ$.

Thus, such processing has the property to restore the complex complement of signals that are included in the range of operation of an orthogonal bandpass filter.

Wavelet filtering of signals requires a sufficiently large number of calculations of multiplication with accumulation, therefore the hardware implementation of this method was carried out on the basis of programmable logic devices (PLD).

To increase the reliability of the analysis and interpretation of the electrocardiogram, we move to the phase plane (Fig. 4a). The method allows you to simultaneously evaluate both the amplitude and speed parameters of the cardiosignal elements, to accurately assess the shape of the electrocardiogramma cycle (ECG) and to determine signs of even the smallest pathological changes in the heart that are invisible in traditional ECG diagnostics [5]. For comparison, we will give the result of the transfer to the ECG phase plane, made in another patient (Fig.4b)

Figure 4. The result of filtering the cardiogram with orthogonal bandpass filter, transferred to the phase plane.

4. Conclusion

Visually, it is possible to see that the paintings have fundamental differences. The data obtained allow us to hope that the use of an orthogonal filter built on the basis of the Morlet wavelet function with the specified characteristics and the translation of the ECG into the phase plane will increase its information content and will help the timely establishment of the correct diagnosis.
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