Classification of the Functional State of the Respiratory System Based on the Spectral Analysis of the Electrocardio Signal

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Abstract. The aim of the study is to develop a method for forming descriptors for neural network classifiers of the functional state of the respiratory system, based on the analysis of slow waves of the time-frequency spectrum of the electrocardiosignal. The essence of the proposed method is to study the interaction of the rhythms of the cardiovascular, respiratory system and higher-order rhythms, which is carried out on the wavelet plane of the electrocardiosignal. The lines are highlighted on this plane, the frequency range of which corresponds to the breathing rhythm. These lines are modulated by VLF (very low frequency) waves, which determine the variability of the respiratory rate. We carry out Fourier analysis of these lines of the wavelet plane and find descriptors for the trained classifier of the functional state of the respiratory system. The signals of slow waves, reflecting the variations in the breathing rhythm, are extracted from the monitoring electrocardiosignal by means of exploratory analysis in the frequency range of the breathing rhythm and subsequent wavelet analysis in the frequency range corresponding to the frequency range of the breathing rhythm. The components of the relevant strings of the wavelet plane are used to calculate descriptors of a trained neural network, which makes a decision on assigning the current state of the respiratory system to the tested state.

Keywords: Cardiac Rhythm, Respiratory System, Systemic Rhythms, Fourier Transform, Wavelet Transform, Respiration Rhythm, Trained Classifier.

1 Introduction

The fundamental property of an organism is the functioning of its systems in certain rhythms, with a certain "rhythmic variability" [1-2]. Respiratory rhythm is formed on the basis of receptor information received from various receptors (for example, chemoreceptors, mechanoreceptors), which allows the central respiratory regulator to select optimal ventilation modes. Respiratory rhythm formation in humans largely depends on their psycho-emotional state, which is due to the influence of the limbic system on the activity of the respiratory center. A number of experimental studies show that the electromyogram of the respiratory muscles is an indicator of the state of the respiratory system. And the electrical activity of the respiratory muscles is an informative parameter in the diagnosis of violations of the functional state of the respiratory system [3-5].

The body's biorhythms carry information about the functional state of its systems and subsystems. Consequently, the analysis of biorhythm variability makes it possible to assess the functional state of the system as a whole. We use electrocardiosignal (ECS) to study biorhythms in a living organism. This signal is unique in that waves of various origins can be observed in it in the form of modulation of the main rhythm of the electrocardiosignal by waves of a higher order. Since the main rhythm of the pacemaker is a quasi-periodic signal, the spectrum of the pacemaker is continuous (not discrete), which makes it difficult to isolate slow waves from it.

Control of the cardiac rhythm is carried out both from the side of the cardiovascular system and from the side of the respiratory system. The sinus node is a self-contained oscillator with a resonant frequency of about 1 Hz. Its frequency can be slowed down (parasympathetic influence) or accelerated (sympathetic influence) under the influence of control factors. The goal of autonomic heart rate control is to stabilize blood pressure (BP). However, not only the autonomic nervous system, but also the central nervous system (CNS) affects the wave structure of the pacemaker.

HF-waves (high frequency waves) are presented in the ECS spectrum with a peak in the range of 0.2 ... 0.3 Hz. The presence of these waves is determined by the respiratory system. The peak of these waves in the spectral region, as a rule, coincides with the rhythm of breathing.

LF waves (low frequency waves) are represented by a spectrum with a peak at 0.1 Hz. These are the so-called L. Traube waves with a period of 10 s. As in the case of HF, several hypotheses have been put forward about the genesis of LF waves. In them, the formation of a rhythm of 0.1 Hz is explained by mechanisms of baroreflex, central and myogenic origin. In practice, the analysis of this rhythm is used to estimate the state of sympathetic regulation of the heart rhythm [6-8].

The VLF (very low frequency) range is the least studied, which corresponds to slow waves with a period of 25… 330 seconds. Many hypotheses explain the genesis of these waves. One of them, described in [8], believes that the variability of the breathing rhythm is based on the mechanism of gas exchange. If this assumption is correct, then the intensity of pulmonary gas exchange, which reflects the rate of oxygen consumption, has the structure of slow waves of the second order and can be used as a marker of the functional state (FS) of the respiratory system. To analyze such indicators of external respiration, long-term recording of pneumogram and registration of pulmonary gas exchange is necessary. It is very difficult to obtain such parameters, since this requires special equipment, with continuous recording of signals at an interval of at least 30 minutes.

2 Materials and methods

The mechanism of changes in the heart rate during breathing is associated with the functioning of the baroreflex system for stabilizing blood pressure (BP). It is known that the heart rate rises with inspiration and decreases with expiration due to changes in pressure in the chest cavity. These processes cause fluctuations in blood pressure [6].

Consider the morphology of the ECS wavelet plane. Figure 1 shows an example of the ECS wavelet plane with a duration of 3 minutes. The image contains 300 lines (wavelets). The lower frequency on the wavelet plane is 0.25 Hz and the upper frequency is 40 Hz. The contrast stripes in Figure 1 correspond to the cardiocycle harmonics: the 1.2 Hz harmonic occupies a 0.64 Hz band; harmonic 2.4 Hz - 0.4 Hz; the 3.6 Hz harmonic occupies a 0.6 Hz bandwidth. Breathing rhythm waves correspond to vertical stripes in the lower part of the wavelet plane. They characterize the variability of the breathing rhythm in frequency.

We will consider one line of the wavelet plane, the dislocation of which corresponds to the respiration rate to assess the temporal variability of the respiration rate. The diagram of this line is shown in Figure 2. It characterizes the so-called energy variability, that is, the change in the intensity of the corresponding harmonic over time.

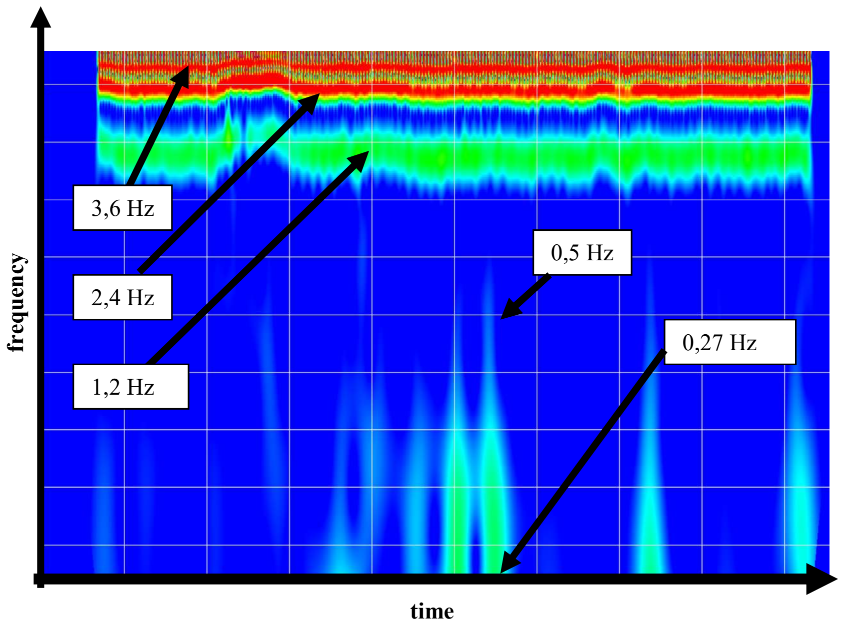

Fig. 1. The structure of the wavelet of the electrocardiosignal.

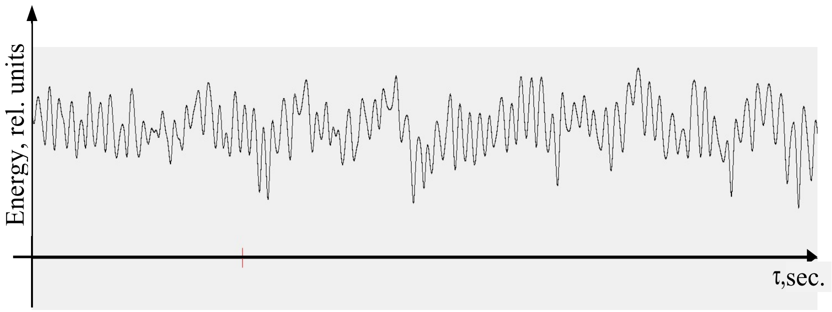

Fig. 2. Plot of the wavelet plane line of the electrocardiosignal corresponding to one of the respiratory rhythm frequencies.

We will also highlight the frequency variability, by which we mean the variability of the frequency band occupied by the respiratory train (frequency packet) over time. According to the results of the analysis of the image in Figure 2, we must identify changes in the selected segments that occur during pathological processes for the formation of descriptors. For this, each segment of the wavelet plane can be characterized by some vector, consisting of the minimum number of components. In this case, we managed to identify two informative zones (waves of the first and second order) with the same parameters of image synthesis. The Fourier spectrum of the wavelet plane line is morphologically similar to the spectrum of the respiratory rhythm train, and morphologically and topologically (in the sense of frequency dislocation) it is similar to the spectrum of the respiratory rhythm obtained by spectral analysis of the pneumogram [8-9].

Summarizing the above, we can present a method for forming descriptors for classifiers of the functional state of the respiratory system by means of spectral analysis of the monitoring electrocardiosignal. The method includes the following processing steps:

- the Fourier spectrum of the electrocardiosignal is determined with the allocation of a train of breathing rhythm;
- frequency band, occupying a train of breathing rhythm is determined;
- the ECS wavelet plane is constructed with parameters allowing to observe lines with breathing rhythm trains on it;
- Fourier spectra of the wavelet plane lines are determined, which correspond to the breathing rhythm frequency band;
- indicators of variability are determined in the spectra of lines of the wavelet plane (indicators of variability in time), corresponding to the respiratory rhythm trains;
- variability indices are defined in lines of the wavelet plane in frequency.

Thus, the method allows one to obtain two groups of descriptors that determine the variability of the breathing rhythm. These two groups of descriptors correspond to two groups of classifiers, the solutions of which are combined by means of an aggregator [10-13].

3 Results

We will consider the process of implementing the method of forming descriptors for classifiers of the functional state of the respiratory system on a specific signal. According to the above method, we must determine the train of the breathing rhythm in the Fourier spectrum of the electrocardiosignal for the formation of descriptors. The parameters for constructing the wavelet plane of the electrocardiosignal should be selected in a such way that the lines corresponding to the frequency range of the obtained breathing rhythm train are reflected on the wavelet plane.

The Figure 3 shows an electrocardiosignal wavelet plane, consisting of 800 lines. Its lines cover the frequency range of the breathing rhythm, which lies in the lower part of the wavelet plane. Discrete electrocardiosignal was obtained with a sampling frequency of 100 Hz. To obtain the wavelet plane, 11000 samples of the electrocardiosignal were used. With such input parameters, the wavelet plane covers the frequency range from 40 Hz to 0.125 Hz.

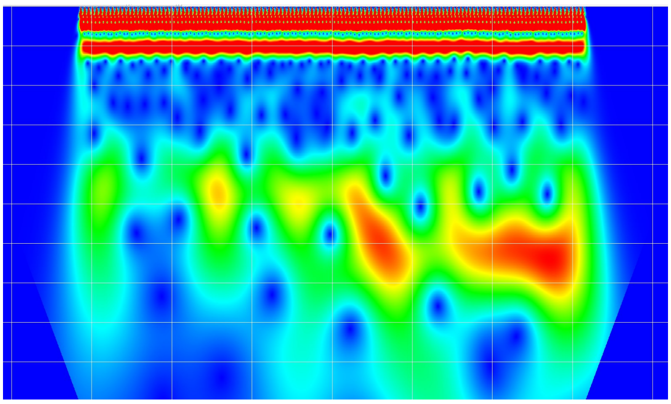

Fig. 3. Wavelet plane of an electrocardiosignal with a second-order slow wave sector with modulation of the respiratory cycle by 15 ... 20 s waves**.**

In the image in Figure 3, the region of the breathing rhythm train covers lines with numbers from 250 to 800, according to the Fourier spectrum shown in Figure 2. The wavelet plane displays rhythms that are modulated by systemic rhythms with a period of approximately 15 ... 20 s. A sweep of several lines in the breathing rhythm sector is shown in Figure 4. Here you can see that the 0.2 Hz breath wave is modulated by a slower wave of higher order, in this case 0.04 Hz.

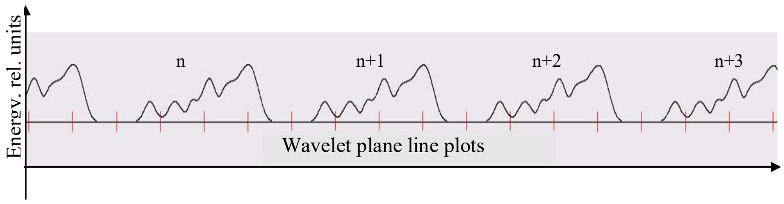

Fig. 4. Scanning of wavelet plane lines in the respiratory rhythm segment: breath wave (0.2 Hz), modulated by 0.04 Hz waves.

Weak classifiers can be constructed for each line from this range. But Figure 6 indicates an excessive correlation of adjacent lines of this wavelet plane, which indicates a weak variability of the breathing rhythm in frequency. This does not contradict either theoretical or experimental studies, since the respiratory rate is modulated by VLF waves, the period of which is 25… 330 seconds (Figure 2).

To construct classifiers of the functional state of the respiratory system, it was proposed to use hierarchical systems of classifiers based on the principle of strengthening the quality indicators of "weak" classifiers [11-13]. The structural diagram of the hierarchical classifier is shown in Figure 5.

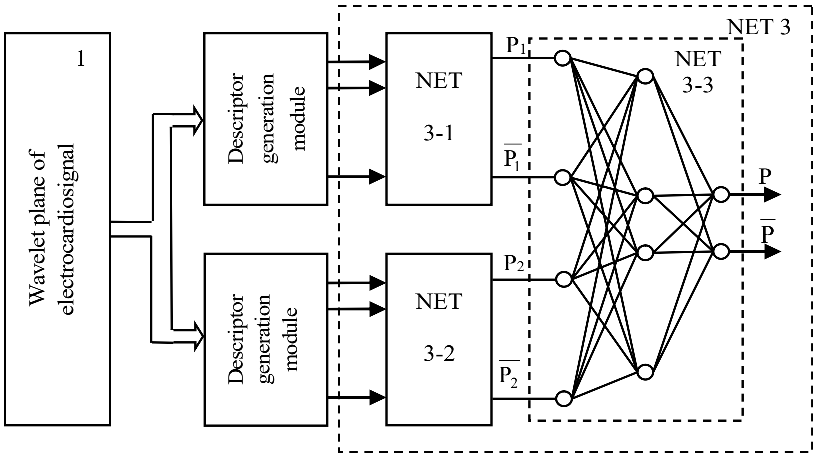

Fig. 5. Structural diagram of a hierarchical classifier**.**

It consists of two autonomous feed-forward neural networks NET 13-1 and NET 13-2 and an aggregating neural network NET 13-3. The indicators of the variability of the selected lines of the wavelet plane in time are used as descriptors of the first autonomous neural network, and the indicators of the variability of the selected lines of the wavelet plane in frequency are used as descriptors of the second autonomous neural network.

4 Discussion

As a result of the analysis of numerous wavelet planes of the electrocardiosignal, as well as the study of the works of other scientists [14-16], we concluded that the assessment of the functional state of the respiratory system depends on the modulation of slow waves of a lower order by slow waves of a higher order. To construct classifiers of the functional state of the respiratory system, we proposed using hierarchical systems of classifiers based on the principle of enhancing the quality indicators of “weak” classifiers [12-13]. The descriptors based on the analysis of the respiratory rhythm variability, the indicators of which can be obtained by analyzing the pneumogram signal and the lung gas exchange indicators, were used as descriptors of "weak" classifiers. It was shown that similar information on the variation of the breathing rhythm can be obtained by analyzing the monitoring electrocardiosignal, the observation aperture of which corresponds to the wavelengths of the VLF range.

The segment of the wavelet plane of the electrocardiosignal was used to determine the indicators of the variability of the breathing rhythm. The lines of this segment corresponded to the frequency range occupied by the breathing rhythm. Since the frequency range of the breathing rhythm is unique for each individual, the Fourier spectrum of the electrocardiosignal was calculated to determine the boundaries, and the spectral composition of its train belonging to the breathing rhythm was analyzed. The parameters for constructing the wavelet plane of the electrocardiosignal were calculated using the found frequency range of the train.

5 Conclusion

The proposed method for the formation of descriptors for classifiers of the functional state of the respiratory system made it possible to highlight from the monitoring electrocardiosignal slow waves corresponding to the rhythm of respiration and a wave of the second order. Analysis of the spectral characteristics of these waves makes it possible to form a space of informative features for classifiers of the functional state of the respiratory system, including classifiers of the premorbid state.

6 Acknowledgments

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