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BIOMETRIC SIGNAL PROCESSING AT RADAR REMOTE DIAGNOSTICS OF CARDIO-RESPIRATORY HUMAN ACTIVITY

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Abstract. Radar units which are able to diagnose the state of living organisms, can find the widest application. The estimation method based on respiration and heartbeat parameters of the person has been suggested. The mathematical modeling for algorithm optimization of obtaining the necessary signals and determination of their spectral characteristics has been carried out.
Key words: signal processing, biometric signal, diagnostic.
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INTRODUCTION

The main advantage of probing is the ability of electromagnetic waves to propagate in a variety of dielectric media with a high degree of inhomogeneity and, in addition, perhaps probing “on reflection” when the receiver and transmitter are located on one side of the investigated object. The study of complex media with a unilateral approach is the main field of application of radar probing.

At present, interest has arisen in the use of methods and means of radar diagnostics of vital indicators of living organisms, which can be solved with the help of radar facilities operating in the range of 1-10 GHz. In this case, by subtracting signals reflected from immovable objects, it is possible to achieve high sensitivity when detecting objects whose boundaries are prone to mechanical vibrations. When the probe signal is reflected from the moving boundary, the phase of the signal will change, which can be fixed in one way or another.

The reasons that cause mechanical vibrations of the probed objects can be of different nature. These vibrations can be forced, and be caused by an external source, or be spontaneous, as in the case of cardiac muscle contraction or respiratory movements of the chest [1].

In human body, objects that perform more or less periodic vibrations are the cardiac muscle (vibrations in the 0.8-2.5 Hz range) and the chest in the process of breathing (vibrations in the 0.2-0.5 Hz range). The amplitude of the heart rhythm component in the recorded signal is not large, and usually does not exceed 5-10% of the amplitude of the respiratory component [2].

In this case, the specific value frequencies are determined by the strenuous activity and the state of the investigated organism. When probing a human body, electromagnetic waves are reflected from the boundaries of division of media having different permittivity, the value of which primarily depends on the percentage of water in a particular organ. The strongest reflections are possible from the boundary division of “air-thorax”, “thorax-lung”, as well as from the boundary “body tissue-blood”. The latter will be particularly contrasting for the heart and large vessels [3].

Remote determination of the parameters of heartbeat and respiration of a living organism is the main task of diagnostics. This problem can be solved by providing rather sensitive radar sensor and by developing the algorithms for filtering background reflections that can mask a useful signal [4].

In the case of remote measurement of the parameters of respiration and heartbeat during the radar probing of a person, great attention must be paid to the suppression of the reflections of the probing and reflected by the target signal.

ASPECTS OF DIGITAL SIGNAL PROCESSING

The use of window functions in harmonic analysis with the use of the Discrete Fourier Transform (DFT) associated with solving problems of estimating the parameters of signals and their detection.

Since the harmonic estimates obtained with the use of the DFT are associated with the conversion of a finite number of discrete signal samples, the detection and evaluation of the parameters of pure sinusoidal signals are possible only when their frequency is a multiple of the reciprocal of the processing interval. Otherwise, the DFT recreates a number of discrete components of a different slowly converging intensity.

To reduce the impact of this defect, the signal at the interval of its processing is multiplied by the smoothing weight functions (windows), which is equivalent to smoothing of the spectral samples generated by the DFT [5].

The choice of the spectral window is dictated by the characteristics of the signal. The weight functions determine the form of the filter characteristic and affect the noise bandwidth, as well as the side lobe level. Ideally, the main lobe should be as narrow and flat as possible to effectively discriminate all frequency components, and the side lobes should have infinite attenuation. The window type defines the bandwidth and the characteristics of the equivalent filter that is used for fast Fourier transform (FFT).

The correct choice of the window shape is also important for providing an accurate analysis of the parameters of the investigated signal in the presence of fluctuation obstacles, and for detecting individual tones in a signal that contains a multitude of harmonic components.

Detailed studies, outlined in the fundamental work of FJ Harris [5], have shown that the windows of Kaiser-Bessel, Barsilon-Temech and Blackman-Harris are optimal from this point of view. The Blackman-Harris window provides suppression of adjacent channels up to 90 dB [6]. This window is the best from the point of view of the attenuation of the side lobes.

It should be noted that the construction of the window function was usually carried out either by using different elementary functions in separate sections of the window, or by adding, multiplying or convolution of several functions, or by optimizing a number of parameters of this function. In [1] the main parameters of window functions are given.

All kinds of window functions [7] used in the processing of signals by means of FFT are symmetric with respect to the middle of the time interval, are limited in duration by this interval, and can be represented using orthogonal cosine basis functions with periods multiple of the time interval.

Modeling.

To isolate the rhythms of breathing and heartbeat, an algorithm has been developed for processing the signal in order to obtain the necessary spectrograms, which allows for in-depth analysis of both harmonics and their mixed products (intermodulations). The complete analysis is important, as the large amplitude of the harmonics of breathing, and sometimes of mixed products, makes measuring the heart rate, especially in the case of the proximity of their frequency ranges, problematic.

When the probing signal hits the target, part of it is reflected because of the high reflectivity of the body [8, 9]. Due to the movement caused by breathing and heartbeat, the thorax expands and contracts periodically, because of which the distance to the antenna $d(t)$ also changes periodically in the region of nominal distance d_0. To monitor physiological parameters, the movement of the body due to both breathing and heartbeat should be determined:

$$d(t) = d_0 + y_b(t) + y_h(t), \tag{1}$$

where $y_b(t)$ - a component of respiration, which is useful to describe in a harmonic form:

$$y_b(t) = m_b \sin(2\pi f_b t); \tag{2}$$

$y_h(t)$ – component of the heartbeat, which can be described by a sequence of symmetrical triangular pulses:

$$y_h = \frac{m_h \cdot \tau \cdot f_h}{2} \left(\frac{\sin[\pi \cdot n \cdot \tau \cdot f_h/2]}{\pi \cdot n \cdot \tau \cdot f_h/2} \right)^2 . \tag{3}$$

In the expressions (2) and (3) m_b and m_h are the amplitudes of movement during respiration and heartbeat; f_b and f_h - the respiratory rate and heart rate, respectively; τ - duration of the triangular pulse.

According to [10], the signal reflected from the biological object can be described as a phase of the received signal:

$$\varphi(t) = \left[2\omega_0 \left(\frac{d_0 + y_b(t) + y_h(t)}{c} \right) \right], \tag{4}$$

where $\omega_0 = 2\pi f_0$ is the circular frequency of the probing signal; c is the speed of light.

The modeling was carried out with the following parameters (Fig. 1): $d_0 = 1$ м, $m_b = 0{,}005$ м and $m_h = 0{,}0005$ м, $f_b = 0{,}3$ Hz and $f_h = 1{,}25$ Hz, $\tau = 0{,}3$s.

First of all, it is necessary to get rid of the constant component, which is proportional to the distance from the radar to the target d_0. One option is to use a filter whose transfer function has the form:

$$F(s) = \frac{s-1}{s}. \tag{5}$$

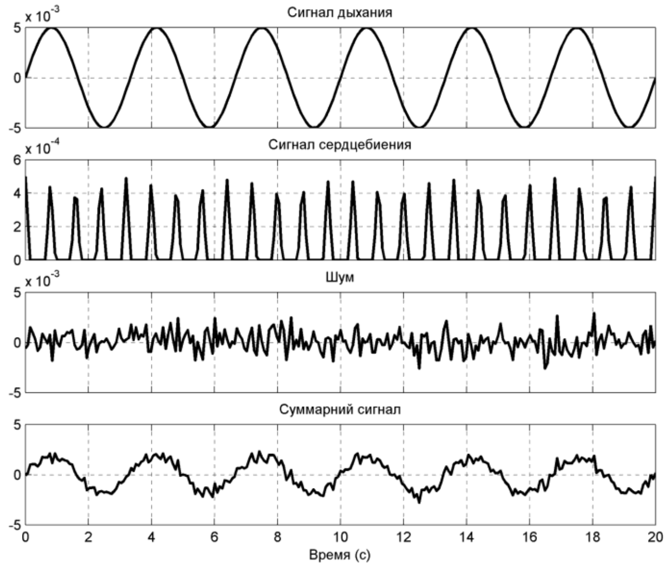

Fig. 1. The received biometric signal and its components.

The signal at the output of such a filter will already be devoid of the component $\frac{2\omega_0 d_0}{c}$ that is part of (4).

To highlight the respiratory component, it is suggested to use a digital non-recursive bandpass filter of the order M = 256 with a bandwidth of 0.2-2.5 Hz. A similar filter with a bandwidth of 0.75-2.5 Hz is used to highlight the heartbeat component. In both cases, the weight function is the Blackman-Harris window. After digital filtering, the signal is fed to an FFT block with a bit depth of 4096. Fig. 2 shows the spectra of the components of the heartbeat and respiration obtained as a result of signal filtration.

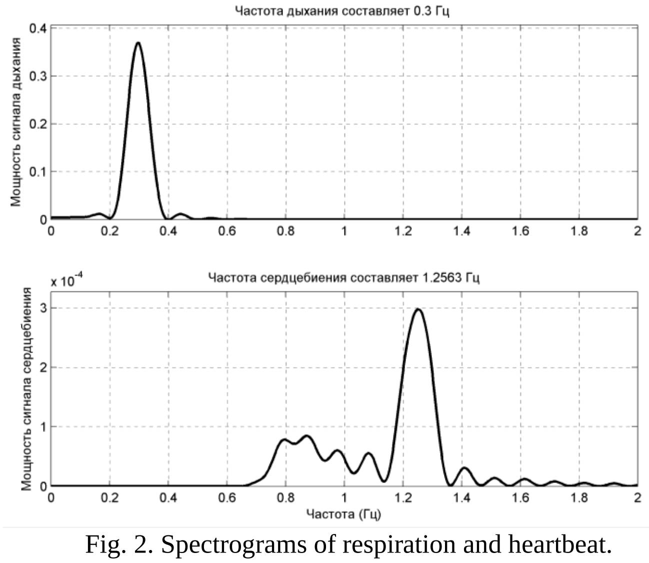

Fig. 2. Spectrograms of respiration and heartbeat.

It can be seen (Fig.2) that application of the selected window function with the subsequent FFT to the obtained phase characteristic (Fig. 1) makes it possible to distinguish the respiration and heartbeat rate frequencies that interest us, and are clearly expressed by bursts at the corresponding frequencies of the spectrogram. This allows us to speak about the effectiveness of using this technique.

However, under certain conditions of the human body, the respiratory rate can be extremely close to the heart rate, which makes it difficult to analyze the parameters of the latter. In most cases, the higher harmonics of the respiratory component have parameters close to the parameters of the heartbeat. To eliminate these components, it has been suggested to apply a harmonic compensator whose frequency characteristic is:

$$H(\omega) = \left(1 - e^{-j\frac{\omega}{f_b}}\right)^K, \tag{6}$$

where K is the number of series cascades with the same frequency characteristics.

The compensator relieves the signal from the harmonics with the frequencies $n \cdot f_b$, and $(n \cdot f_b)^2$, where n is the ordinal number of the harmonic of the respiration signal, and / or the intermodulation components with frequencies that are multiples f_b. However, increasing the order of the filter K also increases the capacity of the compensator, which in turn can adversely affect the accuracy of determining the heart rate.

The use of the compensator can also relieve the signal from the heart beat component, or distort information about it, in the case where the heart rate coincides or will be close to a of the multiple respiration signal frequency. Therefore, the compensator is switched on only when the main frequency of the respiration signal falls within the range of the bandpass filter responsible for filtering the heartbeat component. In other cases, there is no need to use it.

After applying the FFT with a bit depth of 4096 to the received signal, we obtain a spectrogram with a bright splash at a frequency that corresponds to the specified heart rate at the modeling (Fig. 3). The modeling was carried out with $f_b = 0{,}9$ Hz and $f_h = 1{,}25$ Hz .

The obtained result allows to make a conclusion about the expediency of using a harmonic compensator in order to isolate the heart rate from the received signal, in the case when the respiration rate is close to the heart rate.

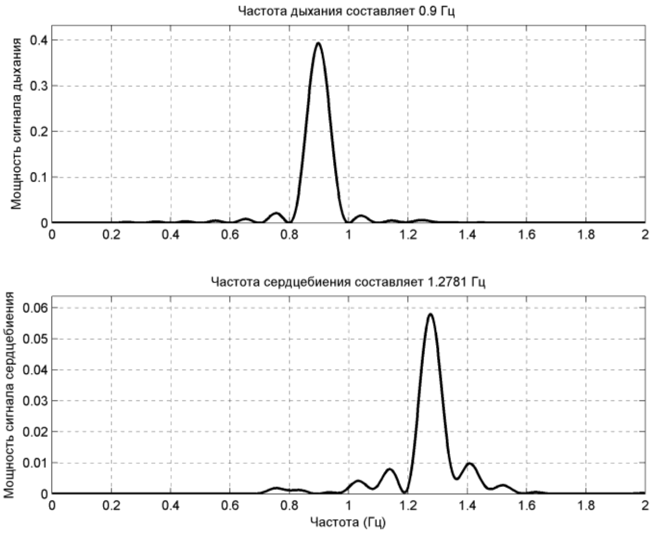

Fig. 3. Spectrograms of the respiration and heartbeat components before and after using a harmonic second-order compensator.

CONLUSIONS

A comprehensive analytical study of the phase spectrum characteristic of the received signal has been carried out, which characterizes the process of respiration and human heartbeat. The respiration rate can be easily estimated at the stage of the signal start filtering. Nevertheless, the amplitude of the movement of the thorax caused by breathing is an order of magnitude higher than in the heartbeat, so in the analysis, the evaluation of a weak heartbeat signal, both in the time and in the frequency domain, is complicated by the presence of harmonics of the respiration signal and intermodulation components between respiration and heartbeat . Since the frequency of respiration and its intensity may depend on the person and the situation, in some cases the frequency of the first harmonic of respiration and / or intermodulation components is close to the heart rate, which complicates the determination of the parameters of the latter. To overcome this problem, the use of a harmonic compensator with a pre-bandpass filtering of the heartbeat component has been suggested, for the automatic removal respiratory components harmonics (as well as for getting rid of intermodulation components).

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