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Experimental research of digital filtering in the separation of breathing signals and heart contractions to assess the control of the driver's condition

Mykhailo Nosach*

Department of Biomedical Engineering and Telecommunications, State University «Zhytomyr Polytechnic», Chudnivska St., 103, Zhytomyr, 10005, Ukraine

Abstract

The article is devoted to the research of the method of digital filtering of a mixture of signals at ultra-low frequencies. A mathematical model of the system has been developed that includes an adequate signal model that really brings the result. The type of filter and the window function that is included in it were selected, and an algorithm for digital filtering of the signal mixture was developed that allows the most accurate selection of the received signal parameters. The obtained research results confirmed the efficiency of the mathematical model and the filtering algorithm of the signal mixture, and also proved their practicality in use.

Schlagwörter/Keywords:
digital filtering, harmonious compensator, breathing heartbeat

Introduction

According to statistics, one of the most common causes of car accidents is driver fatigue. Studies have shown that after just four hours of driving, the reaction speed, as a rule, is reduced by half, and already eight hours of travel show completely catastrophic results – a slowdown of the reaction by six times. And since every car manufacturer has always sought to make their products as safe as possible, after research, active development of a special sensor that determines the level of driver fatigue has begun.

Today, the most common are two types of system implementation. The first case involves measuring the behavior of the sensor on the road, which includes such characteristics as the pressure on the brake and gas pedals, as well as the range of motion of the steering wheel. This type of system is used by Volkswagen, Mercedes, Volvo and Skoda. If we talk about the Japanese market segment, then a slightly different method is used here. That is why the most attention is paid to the psycho-emotional indicators of the driver of the vehicle. For monitoring, sensors are used that are designed to monitor facial expressions, changes in heart rate and breathing. Remote determination of the parameters of the heartbeat and breathing of a living organism is the main task of diagnosis. This problem can be solved by creating a fairly sensitive radar sensor and developing algorithms for filtering background reflections that can mask a useful signal.

Literature analysis and problem statement

Nowadays, interest in the use of methods and means of radar diagnostics of vital indicators of living organisms has sharpened. This problem can be solved with the help of radar tools operating at wavelengths in the range of 3-30 cm (1-10 GHz). In this case, by subtracting the signals reflected from stationary objects, one can achieve high sensitivity when detecting objects whose boundaries are subject to mechanical vibrations. When the probe signal is reflected from the moving boundary, the phase of the signal will change, it can be fixed in one way or another.

From the data available in the literature, the sensitivity of this method, when registering mechanical vibrations in the radio range, can reach 10-9 meters. The causes causing mechanical vibrations of objects are probed, can have a different nature. These fluctuations can be forced, that is, they can be caused by an external source, or be spontaneous, as in the case of contractions of the heart muscle or respiratory movements of the chest. In a person subject to

* Korrespondierender Autor.
E-Mail: boyka79@ukr.net (M. Nosach)

more or less periodic fluctuations, there is a contraction of the heart muscle (frequency in the range of 0.8-2.5 Hz) and chest oscillations during breathing (frequency in the range of 0.2-0.5 Hz). The amplitude of the component of the heart rhythm in the registered signal is small and does not exceed 5% of the amplitude of the respiratory component.

Remote determination of the parameters of the heartbeat and respiration of a living organism is the main diagnostic task. This problem can be solved provided that a sufficiently sensitive radar sensor is created and algorithms for filtering background reflections are developed that can mask a useful signal.

The main goal of the work is to highlight the rhythms of breathing and heartbeat. For this purpose, a mathematical model of the signal processing system was developed in order to obtain the necessary spectrograms. This enables an in-depth analysis of both harmonics and their mixed works (intermodulation). The importance of a complete analysis is proved below, since the large amplitude of the harmonics of respiration, and sometimes of mixed derivatives, makes it difficult to measure the heart rate, especially when they are close to its frequency range.

Materials and methods for researching a mixture of a biometric signal

Signal parameters due to respiration and heartbeat are significantly different. The developed algorithm for processing the generated signal and the information that it carries uses these differences. Signal processing is divided into analog and digital stages (Fig. 1).

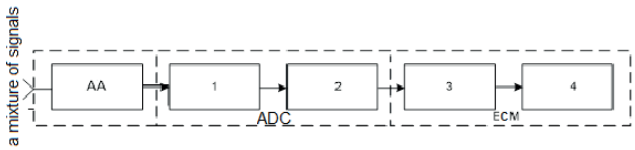


Figure 1: The block diagram of the signal processing: AA – analog amplifier; 1, 2 – analog and digital part of the analog-to-digital converter; 3 – software driver; 4 – work program (ECM – Electronic Computing Machine)

Analog processing consists in double frequency conversion, broadband amplification and filtering, distribution on two channels, and their conversion to digital form.

Digital signal processing is performed in the ADC (Analog-to-digital converter) unit and the computer. At the same time, the computer allows you to apply signal processing algorithms that cannot be implemented in the analog path (for example, logical processing of measurements and analysis of measured results).

The algorithm for processing a mixture of low-frequency signals with subsequent digital processing is shown in Fig. 2.

At the first stage, signals with specified parameters are generated that simulate the process of respiration and heartbeat, as well as some obstacle in the form of noise.

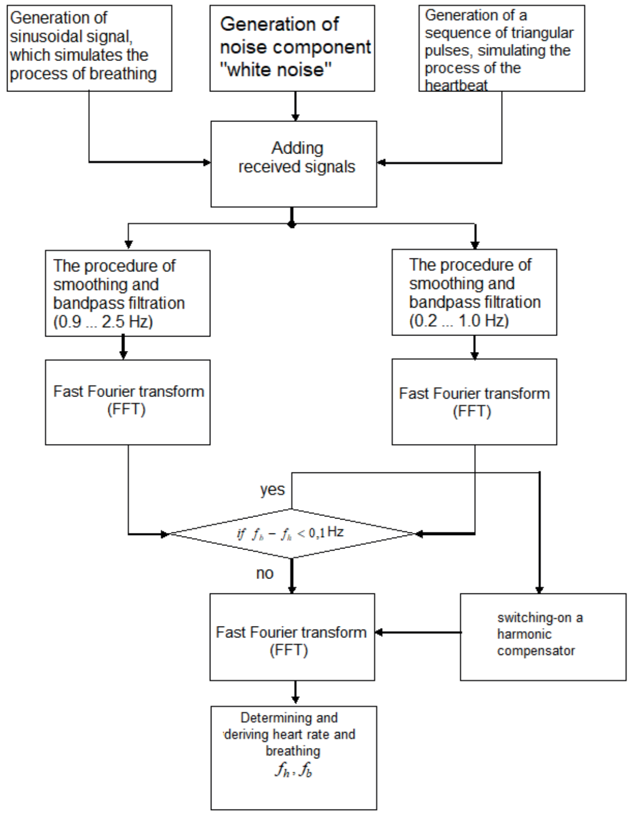


Figure 2: Algorithm for digital filtering of a mixture of bio signals

At the second step, a mixture of signals is obtained that simulates a biometric signal received from a bio-radar. At the third stage, band-pass filtering is performed in order to isolate the components of respiration and heartbeat from the general signal. Further spectral analysis of the received signals allows us to determine the frequency and conduct a comparative analysis of frequencies. This signal also includes a heartbeat signal, which is visible in the spectrum, although it is not so clearly highlighted in the spectrogram compared to the breathing signal. At the fourth stage, additional band-pass filtering is performed to isolate the components of the heartbeat. In the event that the respiration rate, as well as its higher harmonics, falls into the passband of this filter, the so-called harmonic compensator is turned on, the task of which is to shift the spectral components of respiration and its harmonics. Next, a spectral analysis of the received signal is carried out in order to determine the heart rate.

Results of modeling and processing a mixture of a biometric signal

The biometric signal was determined during research simulating a mixture of low-frequency signals. The following simulation (modeling) parameters have been performed in the next way:

– the amplitude and frequency of respiration respectively m_b = 0.005 m and f_b = 0.3 Hz;

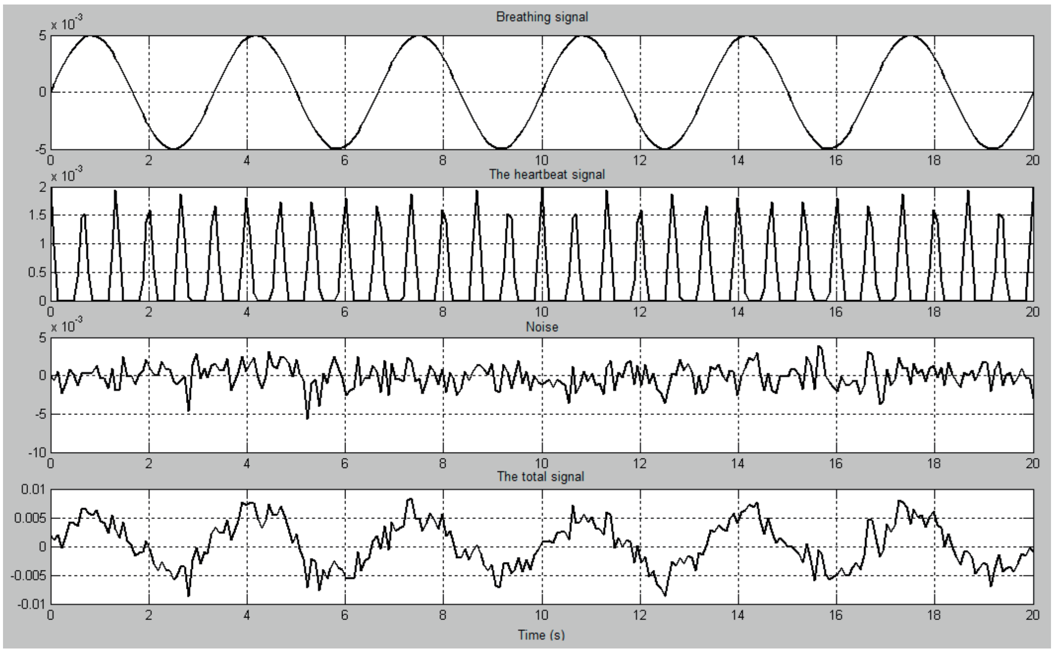


Figure 3: Results of biometric signal modeling

– heart rate and heart rate respectively m_h = 0.0005 m and f_h = 1.5 Hz;
– duration of heartbeat τ = 0.3 s;
– the maximum noise amplitude is 30% of the specified amplitude of the respiratory component.

The simulation results are shown in Fig. 3.

Examples of practical studies of the real mixture of ultra-low frequency signals are shown in Fig. 4.

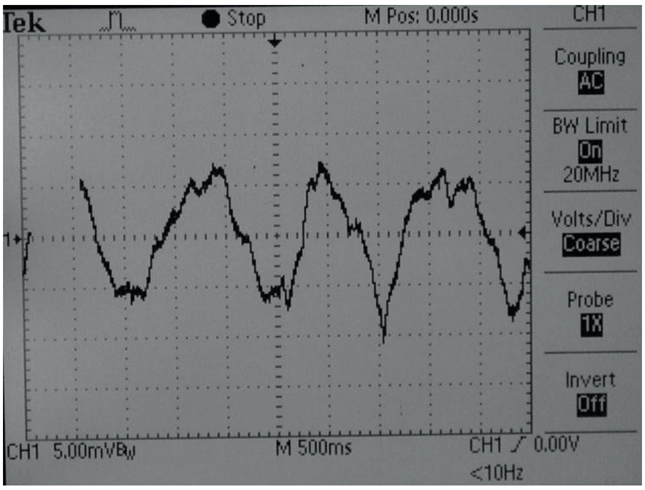


Figure 4: Practical registration of cardiac and breathing activity

Comparative analysis of Fig. 3 and Fig. 4 shows that the shape of the simulation signal generated in the simulation qualitatively in shape coincides with the practically investigated signal. Also, in the study, the time characteristics of the signal at the output of the FIR filter (Finite Impulse Response filter) were studied for various types of window functions.

The parameters of bandpass filters and simulations are as follows:
– passband: 0.2-1.0 Hz (for filtering breathing) and 0.9-2.5 Hz (for filtering the heartbeat);
– weight function: Blackman-Harris window length M = 256 in both cases;
– sampling frequency: F_d = 12.8 Hz;
– research time: T_{max} = 20 s.

Investigation of frequency allocation by the spectral method

The influence of the structure of the window function on the quality of the filtration, can be more qualitatively evaluated not with time characteristic but with the help of spectral analysis.

In Fig. 5 shows the spectrum of the resulting filtering of the signal, which shows that the application to the resulting mixture of signals (Fig. 3) of the selected window function followed by FFT, allows you to distinguish the respiratory rate, which is clearly expressed by a burst at the corresponding frequency of the spectrogram.

After further filtration and FFT, the heart rate spectrogram will also be shown in Fig. 5. Initial modeling conditions:
– passband: 0.2-0.8 Hz (for breathing filtration) and 0.9-2.5 Hz (for heartbeat filtration)
– weight function: Blackman-Harris window, Barlett window, rectangular window in both cases;
– sampling frequency: F_d = 12.8 Hz;
– research time: T_{max} = 20 s;
– FFT bit = 4096.

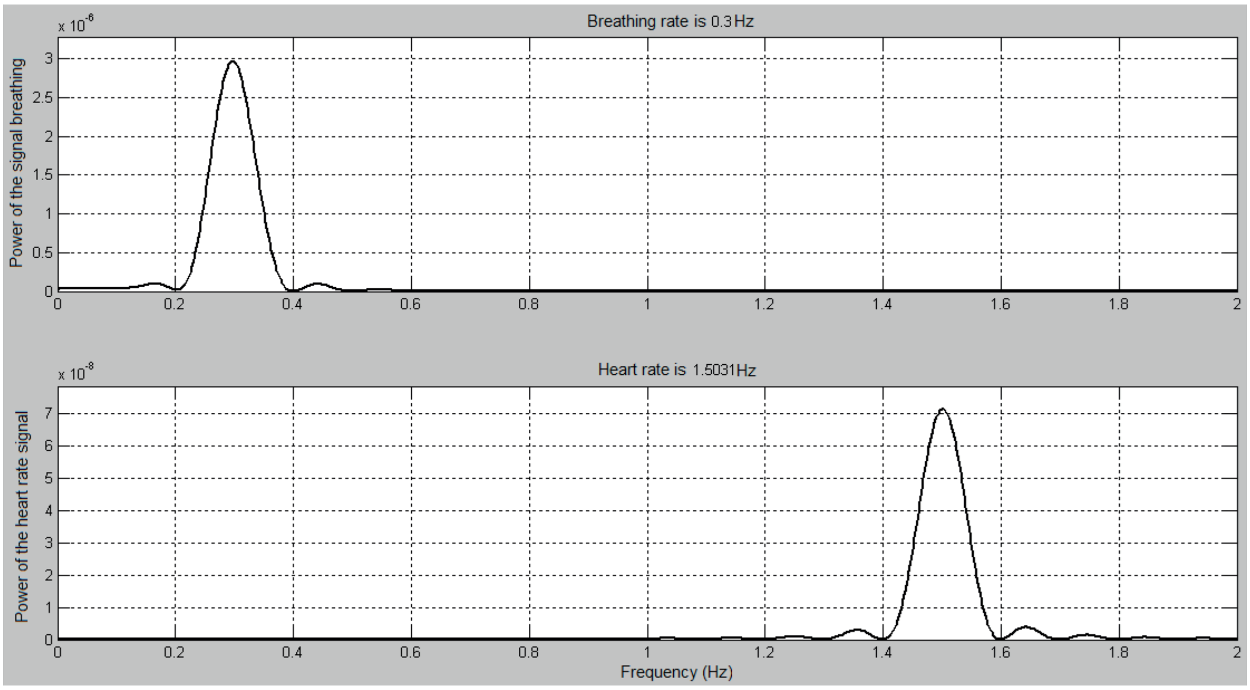


Figure 5: Spectrograms of breathing and heartbeat using the Blackman-Harris window

All of the above allows us to talk about the effectiveness of using this technique.

Research of the principles of using the compensator

Consider the case when the respiratory rate approaches the heartbeat, that is, falls into the passband of the band-pass filter, which is responsible for filtering the heartbeat signal. Let us simulate the case under consideration for given values of the respiration and heart rate, equal to 0.95 Hz and 1.2 Hz, respectively (Fig. 6).

In this case, a harmonious compensator is included in the operation. In Figure 7 shows a graph of the signal (Fig. 6) with preliminary filtering, after passing it through a second-order harmonious compensator.

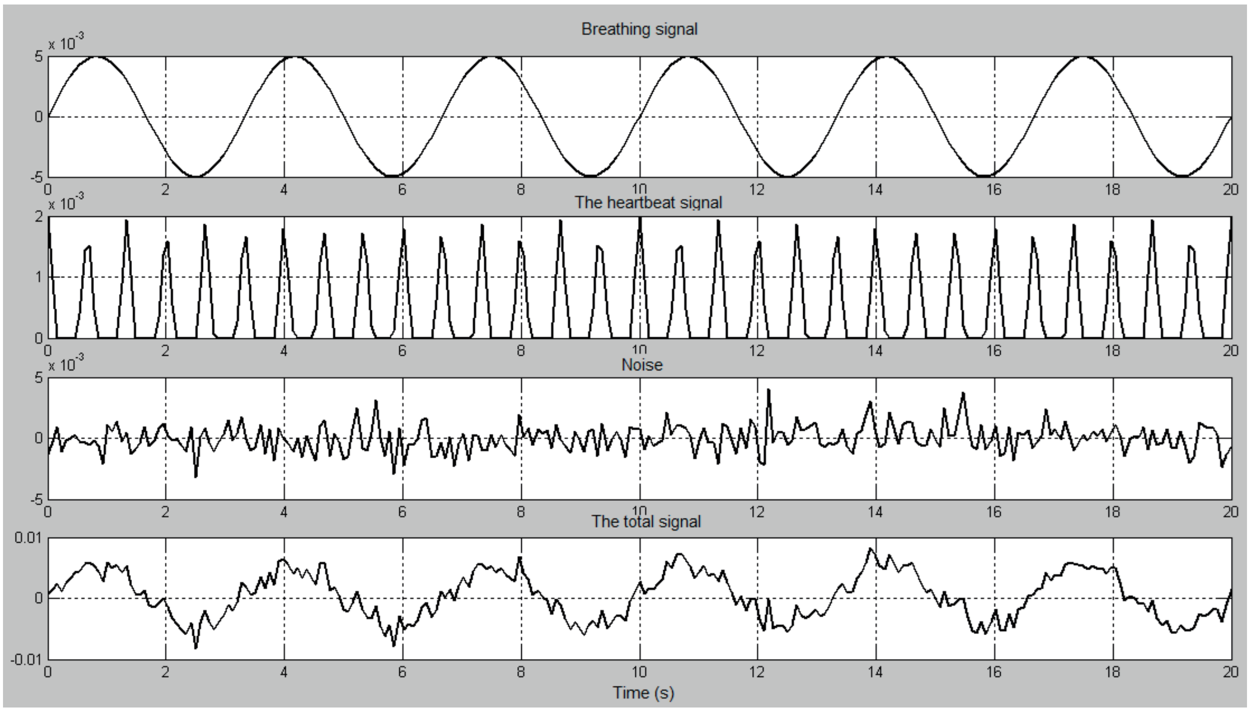


Figure 6: The dependence of the components of breathing, heartbeats and their mixtures on time at frequencies of 0.95 Hz and 1.2 Hz

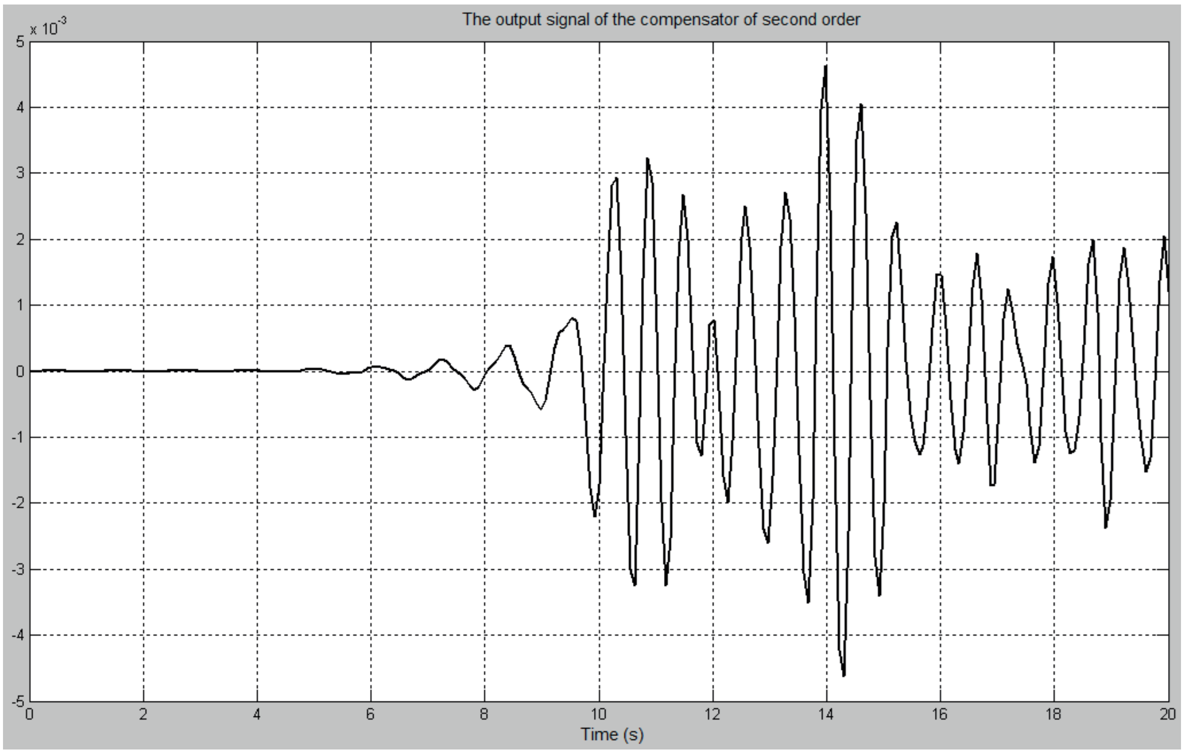


Figure 7: The output signal of the harmonious compensator

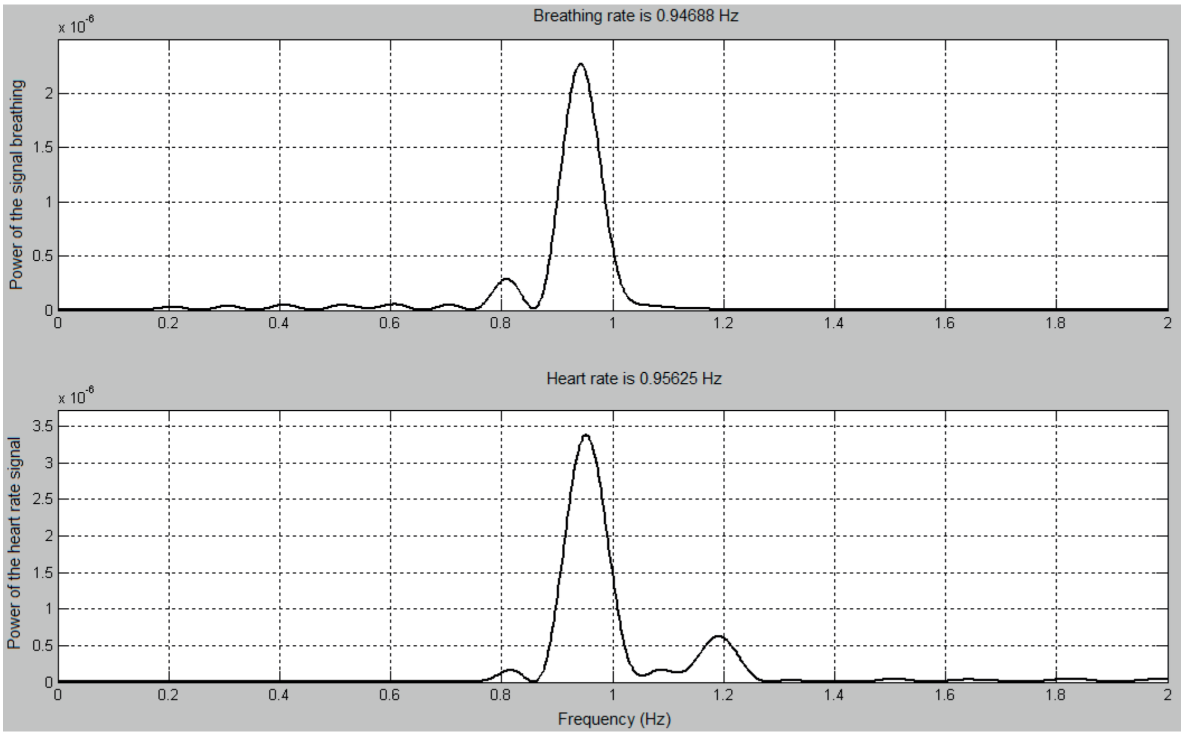


Figure 8: Spectrogram components of breathing and heartbeat to the use of a harmonic compensator

As can be seen from Fig. 8, the breathing signal does not fall into the passband of the first filter and only unfiltered noise components and higher harmonics remain in it (upper graph). However, this signal is fully manifested in the passband of the additional filter, therefore, the component of the heartbeat practically does not stand out against the background of the intermodulation components caused by respiration. This leads to an incorrect determination of the heart rate, for which the value of the respiratory rate is perceived (Fig. 8, lower graph).

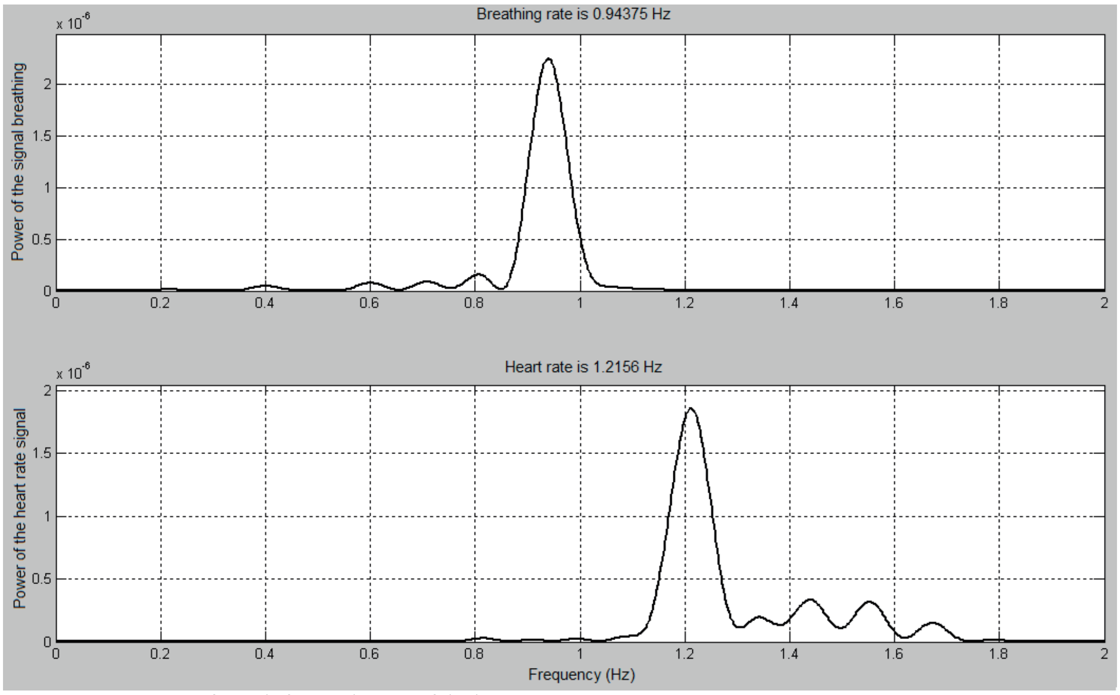


Figure 9: Spectrogram of signal after application of the harmonic compensator

It can be concluded that the presence of a harmonious compensator deprives the signal from harmonics with frequencies of $n \cdot f_b$ and $(n \cdot f_b)^2$, where n is the serial number of the harmonics of the breathing signal and/or intermodulation components with frequencies, which are multiples of f_b.

The result allows us to conclude that it is advisable to use a harmonious compensator in order to isolate the heart rate from the received signal, if the respiratory rate approaches the heart rate.

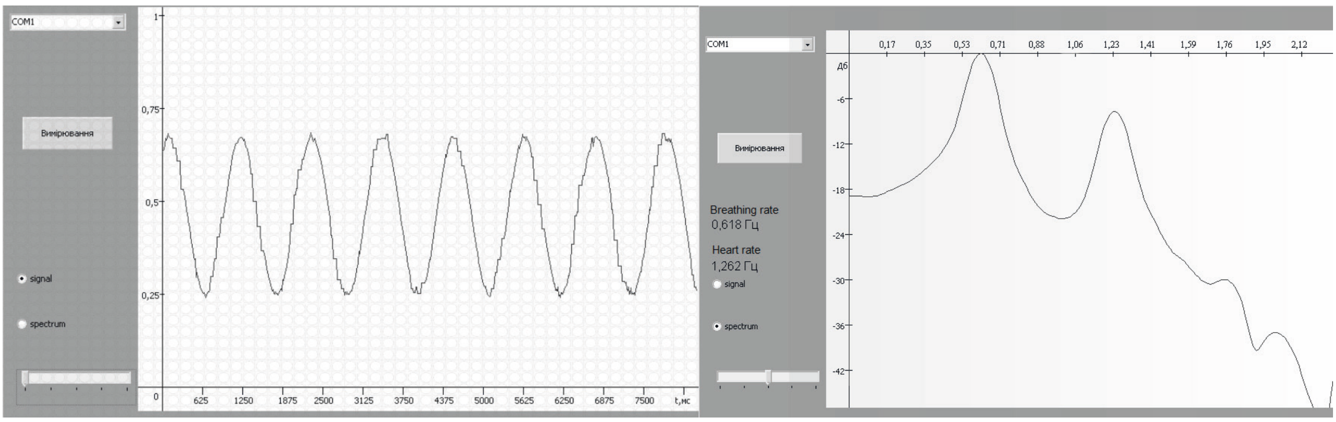
Discussion of research results

To check the reliability of the results of measurements of respiration and heartbeat parameters, a bioradiolocator was used and developed at the Department of Biomedical Engineering and Telecommunications of State University «Zhytomyr Polytechnic».

It was used to compare data processed on a computer with a bioradiolocator (Fig. 10) and simulated signals in the Matlab system.

To measure the intervals between peaks (approximately 4 cycles) using the scaling tools, a data window is set up. Using the I-shaped cursor, the segment is highlighted inside the segment from the beginning of the cycle to its end (total duration of the respiratory cycle). After that, the frequency and amplitude are determined.

The measurements were carried out in three independent cycles in each segment. From the above example, we can conclude that the developed program allows with high probability to reproduce information on human cardiac activity obtained by remote radar method.



a.) b.)

Figure 13: a) received signal; b) spectrogram

Conclusions

The main target of this work was to highlight breathing rate and heart rate from the signal of bioradiolocator. For this purpose, was developed a mathematical model of the signal mixture, which took into account the effect of interference and various frequency ratios of signal components to more accurately determine their parameters.

Having considered all the known methods for separating a mixture of ultra-low frequency signals such as analog, filtering and spectral, the most appropriate method was chosen for each task separately. The filtering method was used to separate the signal mixture, and the spectral method was used to measure the frequency of the signals.

The article presents an algorithm for processing a mixture of low-frequency signals with their subsequent digital processing. Signal parameters due to respiration and heartbeat are significantly different. The developed algorithm for processing the generated signal and the information that it carries uses these differences. Signal processing is divided into analog and digital stages.

Using the Matlab software environment, processing was simulated and the mixture of signals from the influence of interference was separated. The filtering procedure was also described and the choice of the type of filter was justified (non-recursive FIR filter, with the Blackman-Harris window), an algorithm for digital filtering of the signal mixture was developed, which allows the most accurate selection of the received signal parameters.

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