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NOVEL METHOD OF CARDIAC ACTIVITY EXTRACTION IN L-BAND CW RADARS

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Abstract–Azimuthal scanning of the human body by CW Doppler radar is considered. The method of separation of oscillation activities of various internal organs in the microwave Doppler spectra is proposed. Two possible setups with fixed human body + scanning antennas and fixed antennas + rotating human body have been investigated.

1. Introduction

Microwave Doppler radar sensors of biological activity are effective tools for both diagnostic purposes and for use in security and search for life signs during natural disasters [1-3]. It is well known that spectra of Doppler radar signals reflected from the internal organs represent complex mathematical objects [2]. If the simple detection systems of biological activity require only a decision making concerning the presence or the absence of a life, while the non-contact diagnostic systems require to carry out separation of activities caused by various organs. We propose mathematical method and processing algorithm for possible separation of oscillatory activities caused by difficult organs in microwave Doppler spectra. Such an express diagnostic method can be a promising candidate in telemedicine applications.

It is well known, that the spectrum of the signal reflected from oscillating target is identical to the spectrum of FM signal [4,5]:

$$R_x = Be^{i\omega t}e^{i\left[m\cos(\Omega t)t+\Psi\right]}, \quad m=\frac{2v_m}{\lambda},$$

Such consideration can explain the periodic-like spectrum of pulmonic and cardiac activities. Here modulation index m is determined by the amplitude of oscillator $2v_m/\lambda$. Spectrum of FM signal with modulation index m less than 0.5 represents itself main tone and only two sidelobes with opposite phases.

While for the modulation indexes m greater than 1, there are theoretically infinite number spectral components, but we can neglect the members of Fourier series with $n \geq m+2$ [4].

The bandwidth of FM signal for $m \gg 1$ looks like: $2\Delta\omega \approx 2\omega_D = 2m\Omega,$ i.e. the spectral width itself is proportional to the amplitude of oscillator velocity.

It should be noted that only longitudinal oscillations, or oscillations having significant longitudinal component can contribute to the Doppler spectrum. In view of the obvious difference in the symmetry of mechanical activity of the heart (more isotropic) and respiratory organs ("strictly polarized"), the velocity of the oscillations should also be subject to the same symmetry. Thus, the spectral width of respiratory activity should depend on the receiver angle (Fig.1).

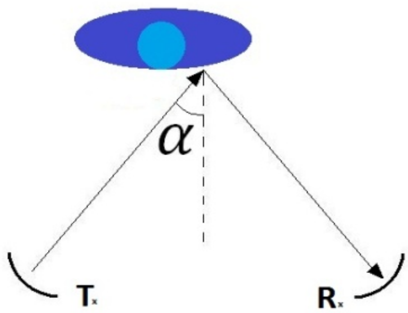

Fig.1. Experimental setup. Tx – transmitter, Rx – receiver (top view)

The direction itself can be taken into account by modifying the expression for the modulation index (3) $m = (2v_m/\lambda)\cos\alpha$, where α is the receiver angle.

It should be noted that the change in pulmonic amplitude spectrum is non monotonic with a change of receiver angle α. The latter is due to the fact that the receiver angle α is included in the respective argument of the Bessel function, which is known to have an oscillating and alternating form. The foregoing makes sense only for the respiratory components of the spectra. Due to the inherent isotropic symmetry, the spectra of cardiac activity should not significantly depend on the receiver angle α. Thus, changing component of the Doppler spectrum can be attributed to respiratory activity.

2. Measurement and Data Processing Methods

CW microwave Doppler radar has been used with power less than 1 mW at 1 GHz band. First experimental series has been carried out with fixed human body and scanning antennas. Separate receiving and transmitting antenna were located at a relative angle 2α. The measurements were performed at three different mutual orientations of the transmitting and receiving antennas: 0°, 90° and 135° (Fig.2).

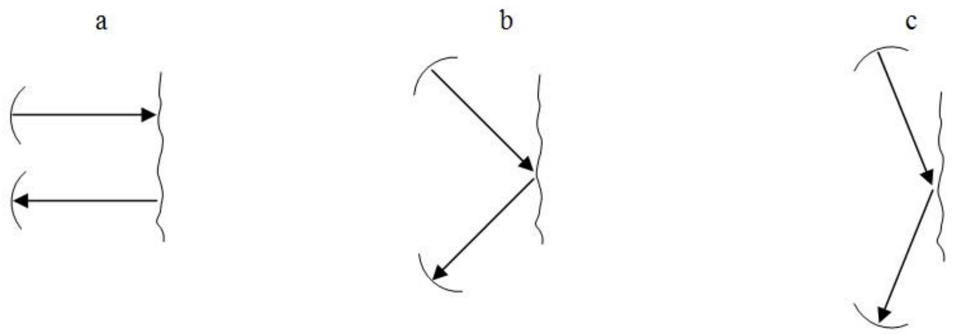

Fig.2. Different spatial orientations of Tx and Rx antennas: a) α = 0°; b) α = 90°; c) α = 135° (top view).

Fig.3 shows the results of two series of measurements corresponding to two different patients. Three different relative orientations of the antennas have been implemented for each of these measurements. In order to extract spectral components which are independent of the direction, the averaging of the spectra over different antenna orientations has been produced (Fig.4).

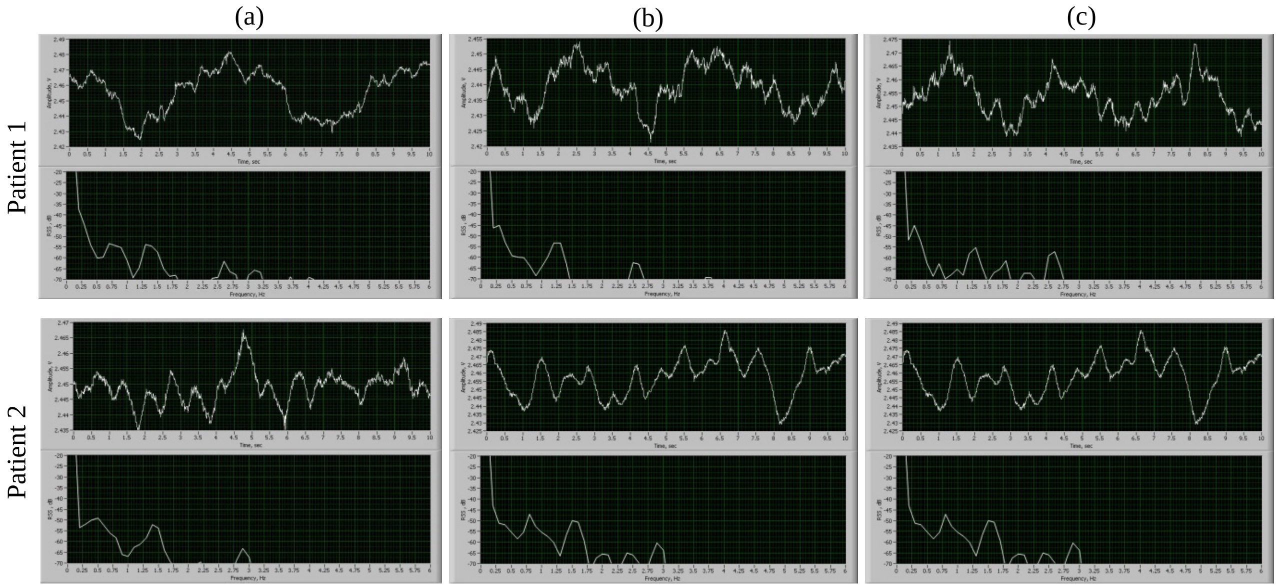

Fig.3. Typical mixed cardiac/pulmonic activities for two patients. Uppers – time domain; lowers – power spectrum of received signal strength (RSS): a) $\alpha = 0°$; b) $\alpha = 90°$; c) $\alpha = 135°$.

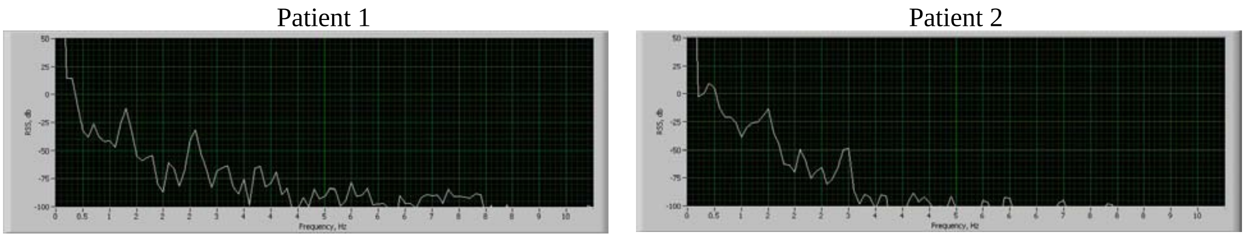

Fig.4. Averaged spectra over azimuthal angle.

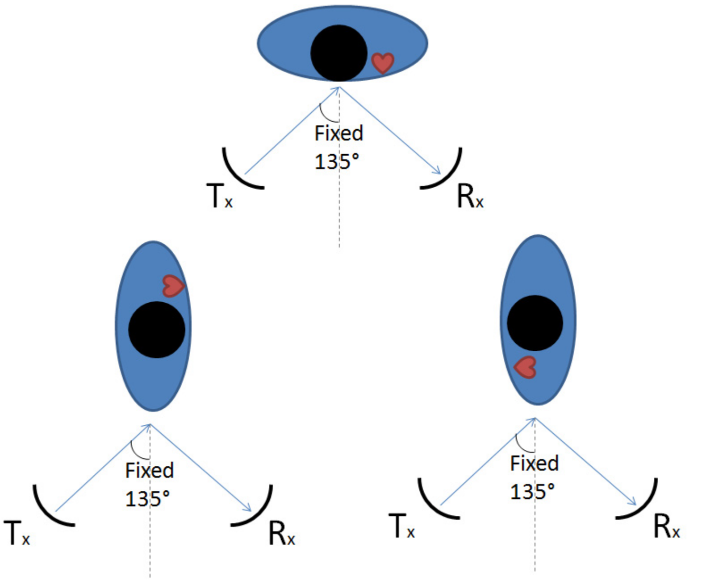

Fig.5. Three relative orientations of human body and antennas.

Second series correspond to setup with fixed antennas of $2\alpha = 135°$ and rotating human body. Three different orientations of the human body have been implemented for each of these measurements. The schema of three relative orientations is presented below (Fig.5).

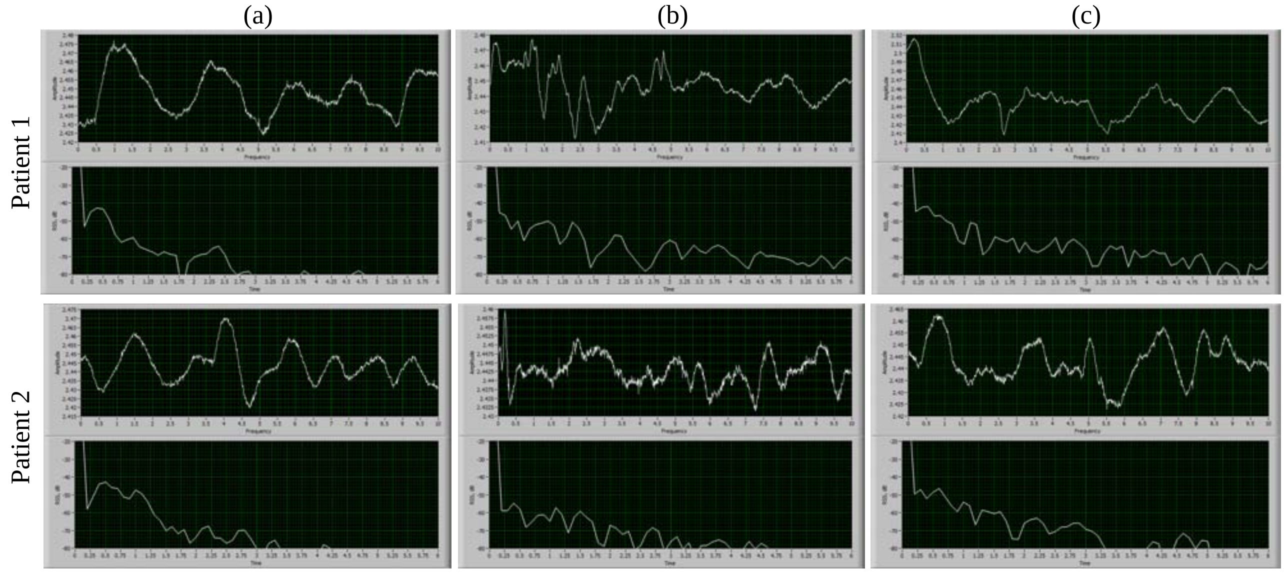

Fig.6. Typical mixed cardiac/pulmonic activities for two patients. Uppers – time domain; lowers – power spectra of received signal strength (RSS) for rotating human body + fixed antennas.

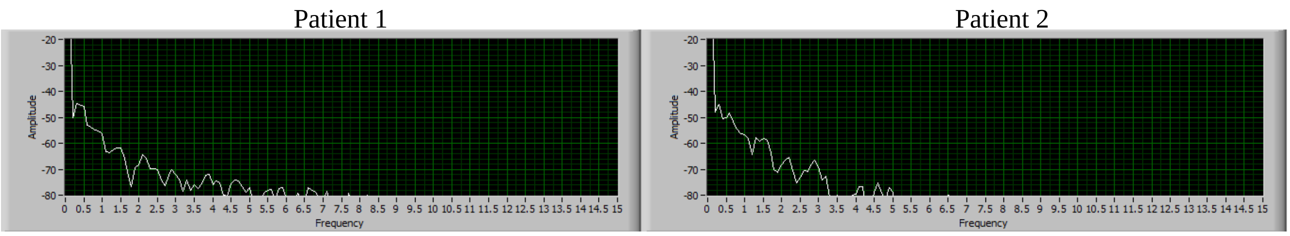

Fig.7. Averaged spectra for rotating human body + fixed antennas over azimuthal angle.

3. Discussion and Conclusion

As it can be seen, the method of averaging of Doppler spectra both over the azimuthal scanning of antennas (Fig.4), and rotating human body (Fig.7) allows us to isolate the spectrum of cardiac activity from a broadband and intense spectrum of pulmonic activity. For comparison, Fig.8 represents an isolated spectrum of cardiac activity which is obtained by breath holding. Qualitative agreement with the results of this method is obvious.

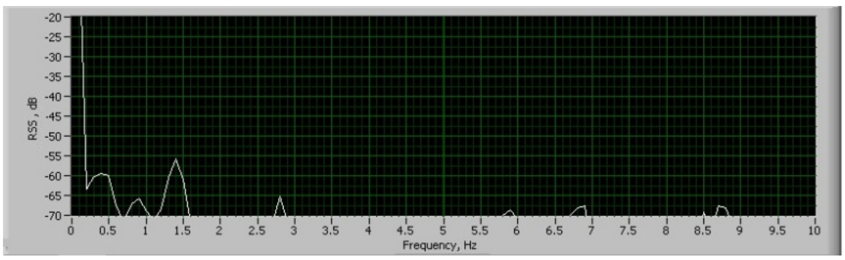

Fig.8. Typical isolated cardiac activity (power spectrum of received signal strength (RSS)).

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