Independent Component Analysis in Bioradar Data Processing

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Abstract— The work contains feasibility study of independent components analysis (ICA) in bioradar data processing. The method was tested on separation of respiratory and heart beat patterns in bioradar signals. A mathematical model of a bioradar signal reflected from biological objects is presented. Mathematical simulation confirmed that ICA is appropriate if observing a single person for separating vital signs patterns even in most challenging cases (e.g., sports bradycardia). In addition, the possibility of respiration pattern extraction from bioradar data in case of biological objects observed simultaneously by means of ICA was tested on models, which confirmed the effectiveness of the proposed method.

1. INTRODUCTION

Bioradiolocation is a relatively new method which may be used for remote monitoring of a biological object vital signs even in case of optically opaque obstacles presence [1]. This technique does not require application of any contact sensors or electrodes. It is based on the reflected radar signal modulation caused by movements of a thorax and other parts of the biological object. Such specific modulation is absent in cases of only static objects (ground features) presence. Bioradars may be used in different areas, among them are: disaster medicine (for detection of survivors beneath debris after natural or technological disasters [2, 3] (the most serious challenge lies in multipath propagation of bioradar signal in rubble which may contain reflectors at all angles); antagonist and hostage localization inside buildings during counter-terrorism operations [4, 5]; remote diagnostics of psycho-emotional state: screening for undue agitation or anxiety during latent or open screening in criminal investigations or at checkpoints [4].

In medicine the most promising area of bioradars application is sleep medicine (somnology) and fall detection of the elderly. The main advantage of bioradar technology in comparison with currently used apparatus is its non-contact nature. The bioradar signal reflected from a biological object at steady state represents a sum of two vital signs patterns: respiration and heartbeat. In applications associated with medical diagnostics or psycho-emotional state evaluation there is a problem of bioradar signal decomposition into respiration and heartbeat patterns. The main challenge in this case lies in the difference of the chest movements amplitude caused by each of these physiological processes.

Respiration movements of thorax and abdomen area with an amplitude of approximately 1 cm play the main role in reflected signal modulation. Movements of the chest wall caused by a heart muscle contraction with an amplitude less than several millimetres also have an impact on the reflected signal, however much smaller compared with respiration. In literature for solving this problem several approaches are proposed: frequency filtering, empirical mode decomposition with additional frequency pre-filtering and rejection filtration [6, 7]. However all algorithms which are currently used for this purpose are not efficient in case if values of respiration and heartbeat frequencies differ less than 0.6 Hz, or heartbeat frequency is lower than 1 Hz, which is a common situation for sportsmen and known as sports bradycardia. To deal with this issue in the present work we propose to use independent component analysis (ICA).

2. METHODS

2.1. ICA Basics

ICA [8] is a computational instrument of data analysis, which allows data interpreting as a combination of statistically independent sources with non-Gaussian distribution. The method may be described as follows. There are n random vectors $x = (x_1, x_2, \dots, x_n)^T$, which are generated as a sum of independent components $s = (s_1, s_2, \dots, s_k)^T$. The goal of ICA is to transform the observed data x into independent components s using a linear transform $s = Wx$. ICA application requires at least n observed mixtures to separate n sources. In present work we use ICALAB toolbox [9] for MATLAB to study the effectiveness of ICA in decomposition of bioradar data into respiration and heartbeat patterns. This toolbox includes several types of ICA methods suitable for different signal processing including medical ones: ECG, EEG, etc.

FJADE (Flexible Joint Approximate Diagonalization of Quadricovariance Matrices) algorithm, which is a part of JADE-algorithms (Joint Approximate Diagonalization of Eigen-matrices) first introduced by Jean-Franois Cardoso [10], was used in the present work. Its performance was tested on mathematical model of a bioradar signal reflected from moving biological object.

2.2. Mathematical Model

To extract two physiological patterns (respiration and heartbeat) from the received bioradar signal for N biological objects ICA needs at least $2N$ observed mixtures of these patterns. That is why at least $2N$ bioradars are needed for solving the problem. For i-th bioradar in case of a single person observation the received signal may be written as

$$u_i(t) = u_0 \exp[-j2\pi f_i \tau_i(t)], \tag{1}$$

where u_0 is the amplitude of the received bioradar signal; f_i is a probing frequency for i-th bioradar; $\tau_i(t)$ is time delay between the received and probing signals:

$$\tau_i(t) = 2\frac{r_i + d_{b,i}\sin(2\pi f_b t + \phi_b) + d_{h,i}\sin(2\pi f_h t + \phi_h)^{2k}}{c}, \tag{2}$$

where r_i is a distance between antennas block of i-th bioradar and the biological object; $d_{b,i}$ and $d_{h,i}$ are amplitudes of thorax movements towards i-th bioradar caused by breathing and heartbeat, respectively; f_b and f_h — the frequencies of breathing and heartbeat; ϕ_b and ϕ_h — the phases of breathing and heartbeat patterns; k — natural number; c — speed of light.

3. RESULTS OF MATHEMATICAL SIMULATION

In present work we tested ICA in bioradar data processing for two different cases: respiration and heartbeat patterns extraction from the bioradar signal recorded for a single examinee; the same problem for a simultaneous observation of two persons.

3.1. Single Person Observation

Problem of heartbeat and respiration patterns separation in bioradar signal for a single person may be solved using different algorithms [6, 7]. However in case of bradicardia (heart rate below 60 beats per minute), which is typical for sportsmen, these algorithms are not always effective because frequency spectrum components of heartbeat and respiration signals are too close.

Here we used proposed mathematical model of a bioradar signal reflected from the biological object to investigate the possibility of solving above-mentioned problem by means of ICA. To separate two components by ICA minimum two signal mixtures are required. So, mathematical simulation was performed as a single person observation simultaneously by two radars (Fig. 1). Phases of the receive signals for the bioradar #1 and #2 were used as two observed mixtures, which are input data for separating two independent sources (thorax movements caused by heartbeat and respiration) by means of ICA FJADE algorithm.

Figure 2 presents the phases of the received by bioradars #1 and #2 signals in case of simulating bradycardia. Mathematical model parameters are: $f_1 = 3.6\,\mathrm{GHz}$, $r_1 = 1.5\,\mathrm{m}$, $d_{b,1} = 1\,\mathrm{cm}$, $d_{h,1} = 1\,\mathrm{mm}$, $f_2 = 3.8\,\mathrm{GHz}$, $r_2 = 1.3\,\mathrm{m}$, $d_{b,2} = 0.7\,\mathrm{cm}$, $d_{h,2} = 0.8\,\mathrm{mm}$, $f_b = 0.3\,\mathrm{Hz}$, $f_h = 0.65\,\mathrm{Hz}$, $\phi_b = 0$, $\phi_h = \pi/3$.

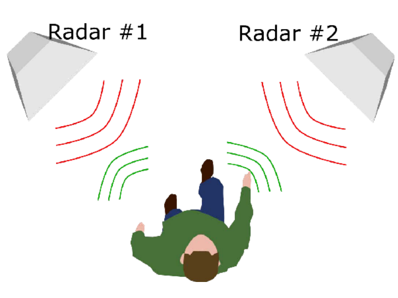

Figure 1: Observing one human with two radars.

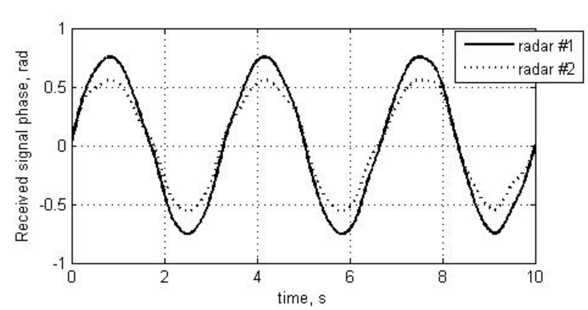

Figure 2: Observed mixtures signals for bioradar #1 and #2.

The result of ICA FJADE algorithm implementation is shown in Fig. 3. It is clearly seen that a heart beat pattern (lower panel) was successfully extracted from bioradar signal and thus separated from respiration pattern (upper panel).

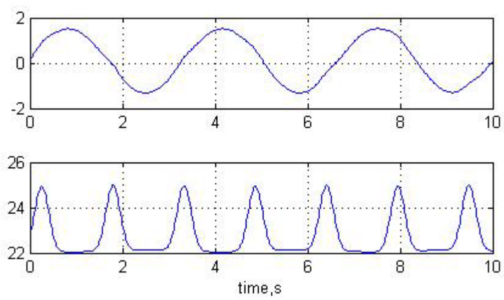

Figure 3: Independent components subtracted by ICA FJADE algorithm.

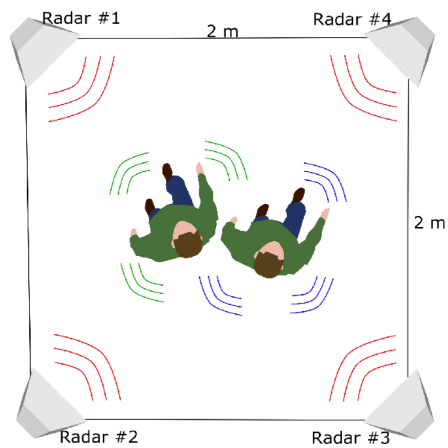

Figure 4: Two humans observation by four radars.

3.2. Two Persons Observation

At present separation of vital signs for two or more persons observed at a time by a bioradar are possible only in case if they are located in different range cells. However, if persons are located at the same distance, separation of their breathing and heartbeat patterns is impossible. In present work we used ICA FJADE algorithm to distinguish between respiration patterns for two closely located persons. To do so at least two signal mixtures are required.

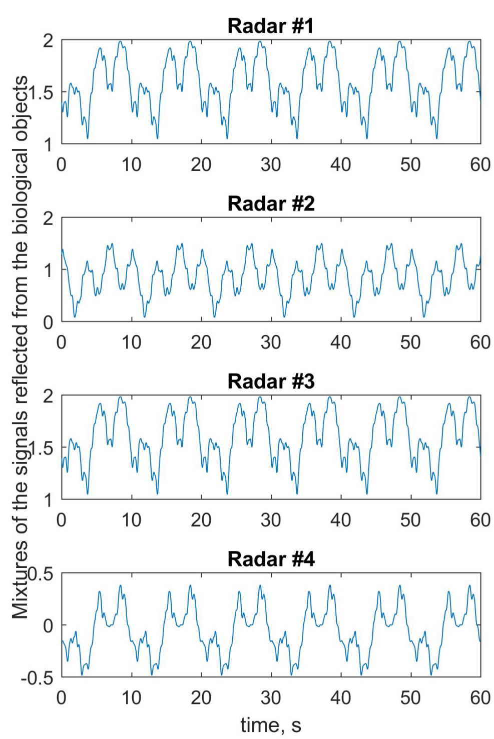

Figure 5: Input signals for ICA.

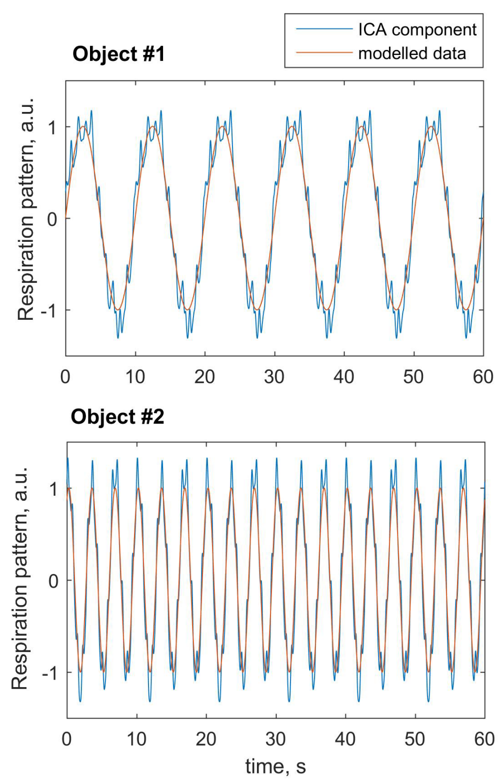

Figure 6: Patterns of modelled respiraion signals and ICA components.

However, in realistic conditions it is possible that one of the examinees would totally shield another one from the radar. In addition, it is known that amplitude of the chest movement differ significantly depending on the direction. Taking into account all these facts for simulating case with two examinees mixture signals for four radars was used. A sketch of the simulated case is presented in Fig. 4. Radars were located at the corners of a square with sides of 2 m. In the centre of the square two biological objects were standing shoulder to shoulder.

For i-th radars receive signal was a sum of the signals reflected from each biological object:

$$U_i(t) = \sum_{k=1}^{N} u_k(t) = \sum_{k=1}^{N} u_0 \exp[-j2\pi f_i \tau_{i,k}(t)] \tag{3}$$

where N is a number of objects (for the present case $N = 2$). Four modelled radars were operating at frequencies 3.6, 3.8, 4.0 and 4.2 GHz. Respiration and heartbeat frequencies for the object #1 were set to 0.1 and 1.0 Hz, respectively, for the object #2 they were 0.3 and 1.5 Hz. In Fig. 5 received by four bioradars signals (mixtures) are shown.

Results of the respiration patterns separation are given in Fig. 6. It is clearly seen that patterns of the model respiration signal and extracted by ICA component are quite similar, although they contains high frequency components caused by heartbeat signals, which do not influence on the accuracy of respiration frequency estimation for both objects.

4. CONCLUSION

This work has presented a feasibility study on the ICA usage in bioradar data processing. The method was tested for separation of respiratory and heart beat patterns in bioradar signals. A mathematical model of a bioradar signal reflected from biological objects is presented. In case of observing one biological object mathematical simulation confirmed that ICA might be used for separation of breathing and heartbeat patterns in bioradar signals even in cases of closely located frequency spectrums of the patterns to be separated or extremely low amplitude of thorax movements caused by heart contractions compared to those caused by breathing movements.

Furthermore, ICA usage revealed the possibility of respiration patterns extraction from bioradar data in case of two biological objects observed simultaneously.

Some limitations of ICA method usage in processing of real bioradar data should be noted. The heartbeat pattern is usually singly influenced by respiration movements. This fact may reduce the effectiveness of ICA performance while these two vital signs separation. Thus, the results of mathematical simulation should be accepted with caution.

In future, the technique is supposed to be tested on realistic experimental data.

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