Проект РФФИ № 17-07-00166а

Разработка новых бесконтактных многоканальных методов для выявления потенциально опасных лиц в местах массового скопления людей.

Основными задачами проекта в 2017г. были:

1) проверка возможности бесконтактной оценки частоты дыхания группы людей при помощи метода биорадиокации,

2) оценка возможности, имея данные лишь об особенностях движения грудной клетки испытуемого при дыхании, выносить суждения о психо-эмоциональном состоянии человека.

В рамках решения первой задачи были проанализированы ситуации одновременного наблюдения двух и трех человек, расположенных в непосредственной близости друг от друга (рис.1 а и б), и на результатах математического и физического моделирования продемонстрирована возможность решения данной задачи при помощи метода независимых компонент.

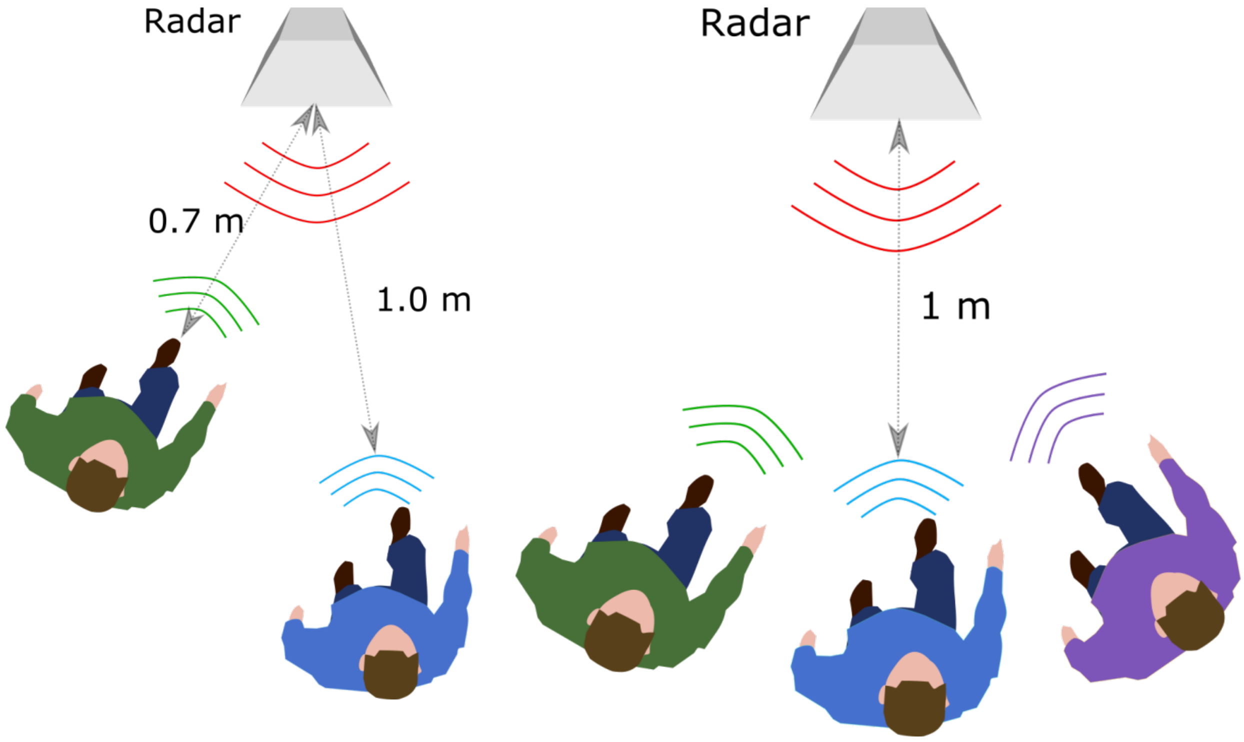

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Рисунок 1 – Схема проведения эксперимента

Для решения второй задачи была собрана база экспериментальных данных с участием практически здоровых добровольцев. Состояние психо-эмоционального напряжения моделировалось путем выполнения добровольцами в уме арифметических операций. Экспериментальные данные затем обрабатывались с использованием методов цифровой фильтрации, математического обучения и анализа динамических систем. В результате был выделен набор параметров рекуррентной диаграммы (детерминизм, уровень ламинарности и другие), которые позволяют классифицировать состояние умственного стресса на экспериментальной выборке с точностью 92 %.

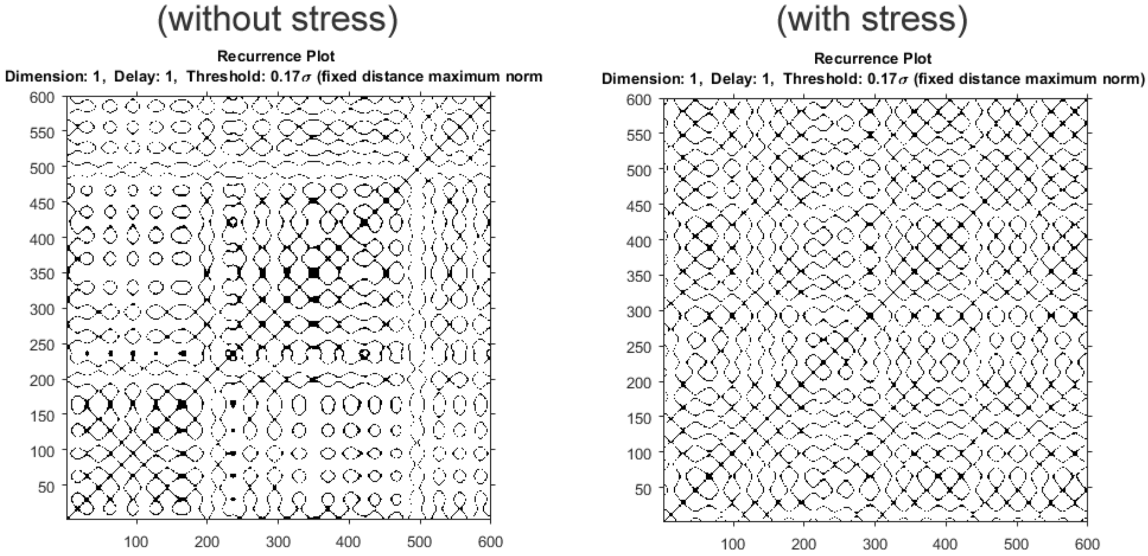

Рисунок 2 – Рекуррентная диаграмма для спокойного и стрессового состояний

Blind separation of several biological objects respiration patterns by means of a step-frequency continuous-wave bioradar

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***Abstract*—This paper presents experimental results to support a new method for blind source separation of several biological objects respiration patterns, which were registered remotely by means of a step-frequency continuous-wave bioradar. The method utilizes independent component analysis. Signals registered by a single bioradar at several probing frequencies are used as input data for independent component analysis as they represents the mixtures of the respiration patterns of all observed biological objects. Two experiments with two and three examinees simultaneously observed were carried out. The experimental results proved that even in case of biological objects located at the same distance from the radar their respiration patterns can be resolved from the signal recorded by a single multi-frequency bioradar.**

***Index Terms*—Blind source separation, Doppler radar, independent component analysis, respiration pattern.**

I. Introduction

Bioradiolocation is a non-contact method which may be used for remote monitoring of a biological object vital signs even in case of optically opaque obstacles presence [1]. The method of bioradiolocation is based on the reflected radar signal modulation caused by movements of the biological object. While the examinee is staying relatively motionless (e.g. during the sleep) this modulation is mainly caused by respiratory muscles and heart contractions. Such specific modulation is absent in cases of only static objects (ground features) presence. Bioradars may be used in a variety of applications [1], [2], [3]: security screening, controlling driver drowsiness, disaster medicine, biology, etc.

In medicine the most promising area of bioradars application is sleep medicine (somnology) [4], [5], and fall detection especially of the old people [6], [7]. The main advantage of the technique is its comfort for the user because no contact sensors or electrodes are needed to be attached to the body, which is extremely important when concerning prolonged continuous monitoring.

There are two main problems that limit the application of bioradars in medicine. First of them is connected with the necessity to separate different physiological process patterns. The radar signal reflected from a biological object at steady state is a sum of two vital signs patterns: respiration and heartbeat. Usually the amplitude of chest movements caused by the respirations is more than ten times higher than the one caused by heart beating, which results in a problem of bioradar signal decomposition into respiration and heartbeat patterns. Different research groups proposed a variety of possible approaches: frequency filtering, empirical mode decomposition with additional frequency pre-filtering [8], rejection filtration [9], and application of independent or principal component analysis [10]. The main problem of all algorithms, which are currently used, is that they have low accuracy for persons with abnormal heart rate (bradicardia).

The second problem that limits the application of bioradars in medicine is concerned with multiple objects observation. This problem can be solved by using bioradars which have a high enough space resolution. However this approach does not work if the examinees are located at the distance closer than the space resolution of the bioradar, which is typical for a majority of practical cases.

In the present work we propose to use independent component analysis (ICA) to perform a blind separation of respiration patterns of different humans in bioradar signal registered in a realistic conditions.

II. Methods and Apparatus

ICA [11] is a computational instrument of data analysis allowing blind separation of data into a combination of statistically independent sources with non-Gaussian distribution by transforming the observed data x into independent components s using a linear transform $s = Wx$. To be applied ICA requires at least n observed mixtures to separate n sources. In present work we use FastICA method from sklearn.decomposition library for Python [12] to study the effectiveness of ICA in decomposing of bioradar data while observing multiple biological objects.

In present study we used for experimenting a stepped frequency continuous wave bioradar BioRASCAN-4 designed at Remote Sensing Laboratory, Bauman Moscow State Technical University, which is operating at 3.6 - 4.0 GHz frequency range [13]. The technical characteristics of the bioradar are listed in Table I. The bioradar has two co-located standard gain horn antennas adopted to emit and receive the electromagnetic signal. The maximum power density radiated by the bioradar is equal to 1.36 μW/cm^2, which satisfies the Russia safety standard for microwave emission of 25 μW/cm^2 in the frequency range of 3-300 GHz (for 24 hours exposure) [14].

For each probing frequency two quadratures (I and Q) were recorded. They represent an observed mixture of multiple

TABLE I
TECHNICAL CHARACTERISTICS OF BIORASCAN-4

Parameter	Value
Number of frequencies	8
Operating frequency band, GHz	3.6 – 4.0
RF output, mW	<3
Gain constant, dB	20
Detecting signals band, Hz	0.03 – 10.00
Dynamic range of the detecting signals, dB	60
Size of antenna block, mm	370x150x150

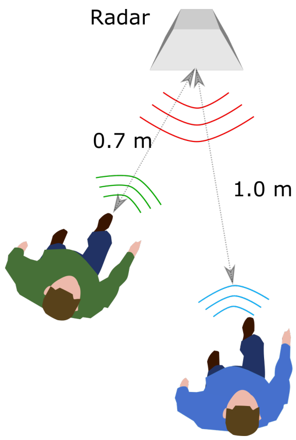

Fig. 1. Scheme of the experiment with two examinees

objects respiration patterns data, which can be used as input data for ICA.

III. EXPERIMENTS AND RESULTS

In the experiments we simulated the cases when a bioradar was used for monitoring respiratory patterns of two or three humans simultaneously observed. It is a common situation for a clinical conditions, when several patients are sharing a single ward. The experiments were conducted without usage of radio frequency absorbing panels to make the experimental conditions similar to the realistic one.

A. Two objects

To prove that it is possible to distinguish between respiratory patterns of two biological objects we carried out the experiment which scheme is presented in Fig. 1. Two examinees were located at the distances of 0.7 and 1.0 m from the bioradar. Both examinees were asked to breath normally for 1 minute. As we need to distinguish between two independent sources (respiration patterns from two examinees) no less than two mixtures of sources are required. The experimental results showed that usage of received bioradar signals at two probing frequencies (four quadratures) as input signals for ICA provides the best performance (Fig. 2) .

The independent sources extracted by ICA are given in Fig. 3. Also the corresponding ground truth patterns (respiration signal registered for each examinee separately) are presented. As it can be clearly seen from Fig. 3 independent

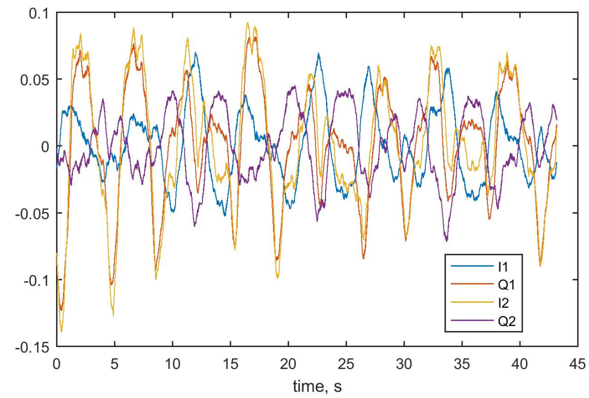

Fig. 2. Observed mixtures for two examinees

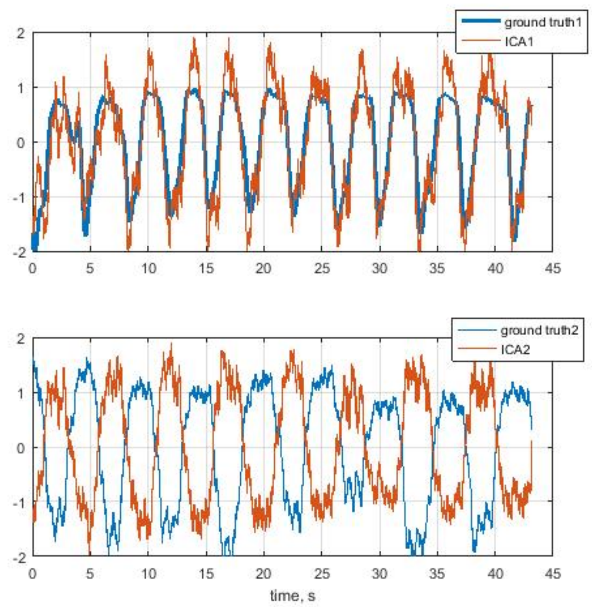

Fig. 3. ICA results for two examinees

components (red lines) extracted from the experimental data are quite similar to the ground truth shown in blue lines. The phase of extracted ICAs may be shifted on 180° as it happened with ICA2 in Fig. 3. However initial phase is not important while monitoring patient respiration pattern in clinics.

B. Three objects

For simultaneous observing of three examinees the scheme of the experiments is shown in Fig. 4. The distances from all three examinees to the radar were relatively equal to 1.0 m. The bioradar signal was recorded for one minute. In such conditions spatial separation of the objects is impossible.

We used six recorded signals (Fig. 5) for different quadratures to resolve respiration patterns of three observed examinees. In Fig. 6 there are the independent sources extracted by ICA with the corresponding ground truth patterns. As

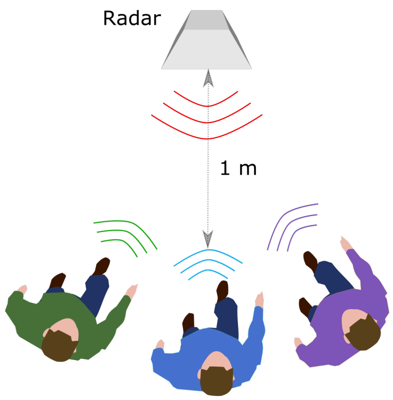

Fig. 4. Scheme of the experiment with three examinees

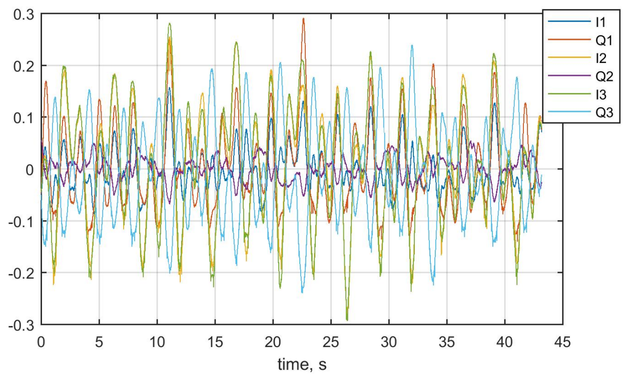

Fig. 5. Observed mixtures for three examinees

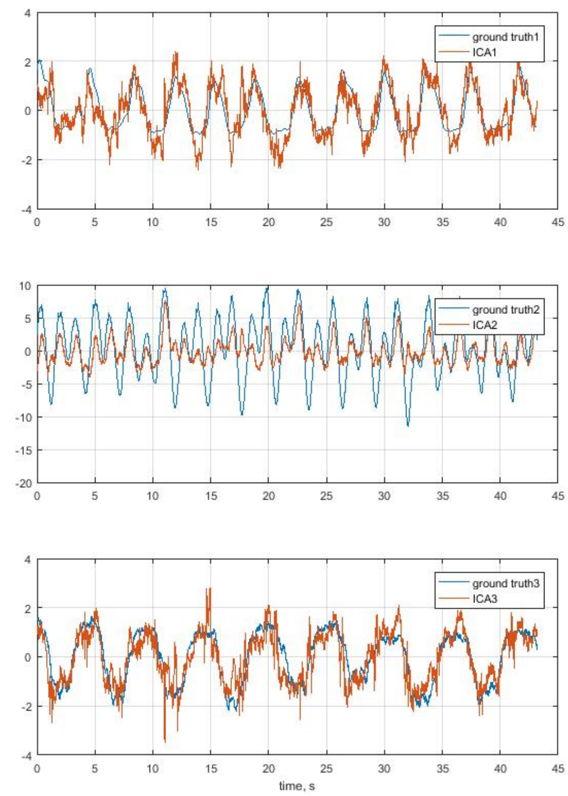

Fig. 6. ICA results for three examinees

one may notice for Fig. 6, ICA2 not quite similar in shape to ground truth2. Nevertheless, it should be mentioned that for measuring respiration frequencies there is no need of precise shape restoration, only positions of respiration peaks are mattered. As Fig. 6 presents, although the extracted by ICA components are noisy, peaks positions in all ICAs are very similar to the ground truth records.

IV. Conclussion

This paper presents experimental results to support a new method for blind source separation of several biological objects respiration patterns, which were registered remotely by means of a step-frequency continuous-wave bioradar. The method utilizes independent component analysis. We tested the proposed method at realistic conditions to separate respiratory patterns of two and three calmly breathing examinees simultaneously observed. Signals registered by a single bioradar at several probing frequencies were used as input data for independent component analysis as they represented the mixtures of the respiration patterns of all observed biological objects.

The experimental results proved that even in case of biological objects located at the same distance from the radar their respiration patterns can be extracted from the signal recorded by a single multi-frequency bioradar.

The work might contribute to the development of noncontact home sleep monitoring systems, which are currently can be used for a single sleeping human only. The future activity will consider expanding the data set and testing the proposed technique for different orientation of the examinees toward antennas of the radar.

Acknowledgment

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