Comparison of a Bioradar and Piezoelectric Sensor in Estimation of Rodents' Respiration Variability

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Abstract— The paper presents a feasibility study on the possible bioradar devices usage for contactless monitoring of the respiratory rhythm of sleeping or anesthetized laboratory animals. Experiments were performed in laboratory conditions on an anaesthetized rat by using a monochromatic radar operating at a frequency of 7.0 GHz. Respiration pattern of a rat was monitored simultaneously by the radar and standard contact piezoelectric sensor. Experimental results analysis revealed a strong linear correlation between respiration frequency estimates for both methods. The Spearman correlation coefficient is 0.97.

1. INTRODUCTION

Bioradiolocation is a method of remote estimation of biological objects vital signs by means of radar [1]. The possibility of radars usage for this purpose was discussed since 1970s [2, 3]. The basic operation principle of bioradiolocation relies on the fact that an electromagnetic wave re ected by a thorax of the biological object is characterized by a phase modulation which may be caused by respiration movements, heart muscle contractions, etc.. At present bioradars turn out to be promising tools in different areas such as military, security, and healthcare. Moreover, method of bioradiolocation may be also employed in pharmacology and zoo-psychology when studying new medicines or conducting behavioral tests for measuring the loco-motor activity and vital signs of animals [4, 5]. The goal of the present work is to investigate the feasibility of radars usage for monitoring of the sleeping animals breathing pattern and verify respiration patterns recorded by bioradar using the same pattern recorded by a standard contact method. Implementation a novel remote monitoring method in clinical practice requires its mandatory verification with standard contact methods. To the best of our knowledge, it has not yet been done for bioradar application in rats or other small laboratory animals. In such cases verification procedure is quite a challenging issue, because all standard methods, which are used in clinical trials to control the physiological parameters of laboratory animals, are contact or invasive. The main drawbacks of them are the necessity to restrain the animal for data collecting or even to conduct operation for telemetric sensors implantation. It worth mentioning that there are standard clinical devices for whole body plethysmography [6, 7] which allow contactless estimation of animals respiration parameters. However their usage is undesirable for verification of bioradar signal because the parts of the device may cause the additional clutter in the recorded bioradar signal. These factors make a contactless and low-cost bioradar method for prolonged monitoring of sleeping animal respiration pattern, which can be applied for different types of animals, up-to-date. This method may be handy for monitoring the respiration pattern of the animal after the administration of new medicines and while testing new approaches for treating different sleep breathing disorders, for which rodents continue to be the most popular biological model to use [8, 9].

2. MATERIALS AND METHODS

At present study as a bioradar a continuous wave radar with one helical antenna operating on 7 GHz frequency was used. Its simplified scheme is presented in Fig. 1.

The radar was designed at Remote Sensing Laboratory, Bauman Moscow State Technical University (Moscow, Russia). Its technical characteristics are as follows:

- maximum energy flux density: 1.25 μW/cm^2;
- dynamic range: 100 dB;
- analog bandwidth: 0.1...20 Hz;
- sampling rate: 200 Hz.

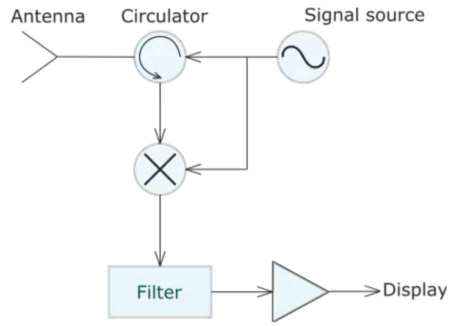

Figure 1. CW radar scheme.

For verification purposes we used standard contact sensor TN1012/ST (AdInstruments, Australia) [9]. It uses a piezoelectric element to convert force applied to the active surface of the transducer into an electrical analog signal. This sensor was designed to measure finger pulse of humans, however it may be also applied for monitoring small animal respiratory activity. A piezoelectric sensor (PES) is placed on the elastic belt as it is shown in Fig. 2. The TN1012/ST sensor was connected to PowerLab Pod, signal from which was recorded with the sampling rate of 200 Hz using LabChart software.

Figure 2. Piezo-electric sensor for contact sensor TN1012/ST [9].

3. EXPERIMENTS

Experiments were conducted at the Institute of Higher Nervous Activity and Neurophysiology of Russian academy of science (Moscow, Russia). In the experiments one male Wistar rat (four months old) was examined.

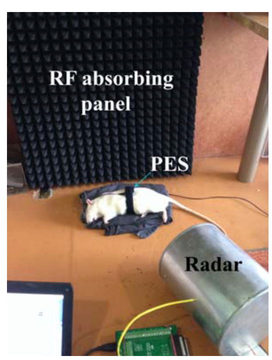

Figure 3. Photo of the experiment.

The animal was intraperitoneally administered with the chloral hydrate anesthetic used in routing tests. It prevented the rat from shifting off the contact sensor, which was fixed on the belt wrapped around the thorax of the animal. During the experiment the radar was located at the distance of 0.3 m from the anaesthetized rat as it is shown in Fig. 3. Such a short distance was chosen due to the relatively small scattering cross section of an animal. Also we used RF absorbing panel placed behind the rat to reduce the clutter.

Signals from contact sensor and bioradar were recorded simultaneously. The duration of each record was 10 min. Three experimental records were made.

To synchronize the respiration pattern records for contact and non-contact methods synchronizing movement artifact was used: operator slightly pressed piezo-electric sensor, which results in artifact in both records (Fig. 4).

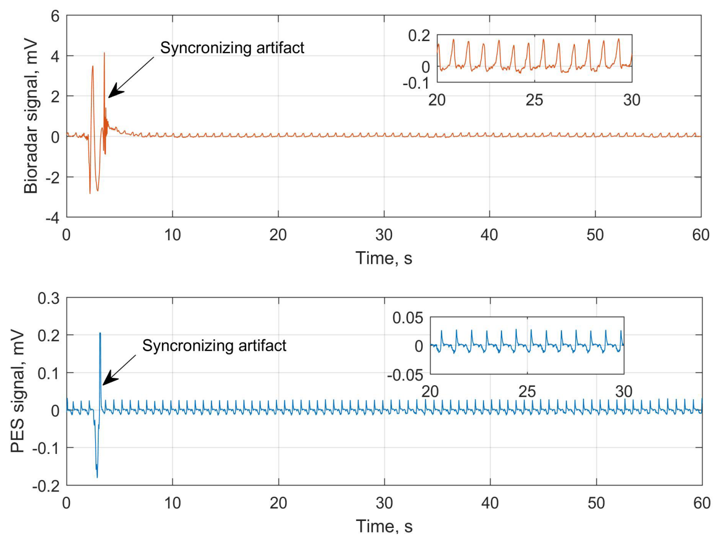

Figure 4. Respiration pattern recorded by the radar (upper panel) and the contact sensor (lower panel). The insets show the signal over the interval [20, 30] s, while black arrows denote sincronizing artifacts.

4. DATA PROCESSING

Experimental data processing software has been designed using MATLAB environment. It consisted of five steps (Fig. 5):

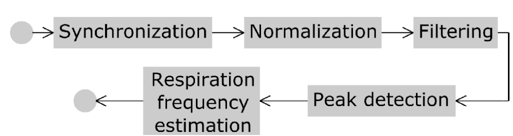

Figure 5. Processing algorithm scheme.

4.1. Signals Synchronization

On this stage the signals recorded by the radar and PES were shifted in time in such a way to make their maximum values fall in the same time interval. Since respiration signal could not be analyzed in the presence of the movement artifact, first 5 seconds of both synchronized records were not used in further analysis.

4.2. Normalization

As it is clearly seen from Fig. 4 normalization of respiration records for both contact and non contact sensor was needed. We used min-max normalization.

4.3. Filtering

This stage consisted of a band-pass filtering. For both records the 7th order Butterworth filter was used. As we were interested in detecting respiration pattern of small animals (e.g., rats or mice) filter bandwidth was chosen to be [0.5, 5.0] Hz, which corresponded to the process of interest frequency band.

4.4. Peak Detection

Anesthetic administration may suppress the respiratory center activity, which leads to irregularity of the respiration pattern. In present work for correct peak detection we used complex algorithm finding local maximum by using the additional parameters: minimum peak height (MPH) and minimum distance between the peaks (MPD).

The values of these additional parameters were chosen as following:

- MPH is equal to a 0.25 level of the average values of the local peaks;

- MPD is twice less than average peak distance for the current record.

The results of the first four stages of the algorithm are shown in Fig. 6.

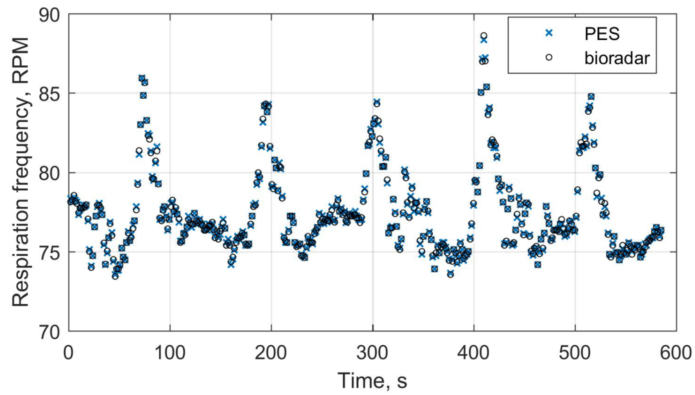

Figure 6. Respitarion frequency for radar data (black circles) and PES data (blue crosses).

For comparing respiratory frequency estimates for PES and bioradar signals listed below indexes were used. The first one was the absolute error (in RPM), defined as:

$$\mathrm{Error}(k) = \mathrm{RF}_{bioradar}(k) - \mathrm{RF}_{PES}(k), \tag{1}$$

where $\mathrm{RF}_{bioradar}k$ denotes the RF estimates for bioradar data in k-th time window, $\mathrm{RF}_{PES}(k)$ — the same parameter for PES signal.

The second index was the Bland-Altman plot with limits of agreement $[\mu - 2\sigma, \mu + 2\sigma]$, where μ is the average absolute error parameter, and σ is a standard deviation. The third index was Spearman correlation coefficient between RF estimates for PES and bioradar signals.

5. RESULTS

The Spearman correlation coefficient for the estimates of respiration frequency done by the bioradar data processing and PES as a standard contact method was 0.97. It was used instead of Pearson coefficient because respiration frequency estimates for radar and PES were not normally distributed.

Figure 7 shows the scatter plot between respiration frequency values for PES record and the associated estimates for bioradar data. It is clearly seen that there is a strong linear correlation between RF estimates for both methods.

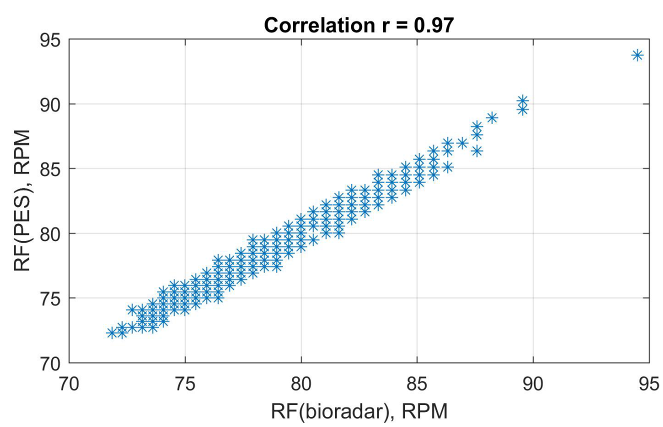

Figure 7. Correlation field of RF PES-bioradar.

6. CONCLUSION

The work has presented a feasibility study on the possible bioradar devices usage for contactless monitoring of the respiratory rhythm of sleeping or anesthetized laboratory animals. Experiments were performed in laboratory conditions on an anaesthetized rat by using a monochromatic radar operating at a frequency of 7.0 GHz. Respiration pattern of a rat was monitored simultaneously by the radar and contact piezo-electric sensor. Experimental results analysis revealed a strong linear correlation between RF estimates for both methods. The Spearman correlation coefficient was 0.97.

Some limitations of the study should be noted. The dataset is small and contains data for only one orientation of the animal toward the radar antenna. Thus, the results should be accepted with caution. The future activity will consider expanding the data set and investigating the possibility of detection respiration pattern and its peculiarities for other laboratory animals.

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