A Feasibility Study for Circadian Rhythm Monitoring via a Continuous-wave Radar

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Abstract— The paper deals with a problem of a remote prolonged monitoring of laboratory animals circadian rhythms. To solve it a continuous wave bioradar operating at 7 GHz is used for non-contact monitoring of rats respiratory pattern and movement activity. The proposed bioradar data processing algorithm automatically detects time intervals of the animal active state and estimates respiration pattern for the rest of the record. The features extracted from the bioradar signal are utilized to classify wakefulness and sleep. The EMG and EEG data analyzed by an experienced biologist are used to train the classifier and test its performance. As a result the accuracy of 82% for 2-stages classification (wakefulness/sleep) has been achieved for bioradar data with the designed classifier.

1. INTRODUCTION

Circadian rhythms studied by chronobiology are due to biological clock activity and allow living organisms to deal with regular environmental changes and anticipate them. Disturbance of these rhythms can influence the general well-being of the living organism and results in development of different health disorders such as insomnia, depression, obesity, diabetes, etc. [1, 2]. The great impact of abnormal circadian rhythms on the quality of life results in growing amount of this problem studies, the majority of which are conducted on biological models. Small laboratory animals are still widely used as biological models while testing new medicine, toxic agents or hazard factors. The most popular animals are rodents (e.g., rats and mice), because of handling simplicity, and fast reproduction rate.

One of the core physiological states partially but sufficiently regulated by intrinsic clock is sleep. The distribution of sleep and activity throughout 24 hours could provide researchers with significant data on the clock functioning. The standard experimental procedure for monitoring wake/sleep slates in rodents involves recording of electroencephalogram (EEG) and electromiogram (EMG) via implanted electrodes. The main drawback of such method is a necessity of preliminary surgery for electrodes implantation, which is a time and labor consuming task involving ethical issues.

The above listed facts make development of non-contact methods, which will be suitable for automatic wake/sleep states and activity monitoring in different animals, an up-to-date task. In fact, noninvasive methods for locomtor activity tracking in rodents are commonly used tools to study their daily rhythms. There are a plenty of techniques, which may be helpful: running wheels [3, 4], stabilimeters [5], and video-tracking systems [6]. It is worth mentioning that the wheel-running method is suitable only for specific types on animals, while video-tracking systems cannot be used behind optically opaque obstacles. In addition, there is a possibility to monitor circadian clocks in vivo by using optical reporters [7], but this technique is applicable for genetically modified animals only.

The goal of the present work is to investigate the possibility to apply continuous wave bioradars for classification between wakefulness and sleep state of the animal during prolonged experiments. The method of bioradiolocation has already been proved feasible to be employed in pharmacology and zoo-psychology by measuring the loco-motor activity and vital signs of animals [8–10]. This paper gives a comprehensive description of a bioradar method, which allows performing sleep/wake classification.

2. EXPERIMENTS

At present study we used a continuous wave bioradar with a single helical antenna operating at frequency of 7 GHz. The bioradar is the same to the one used in our previous studies [10]. 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.

During the experiments the box with the animal was observed by a web-camera Genius eFace IR (Logitech, Switzerland). These video records were used in further bioradar analysis to distinguish between different movement patterns. In addition, we lighted up the experimental field by an infrared diode. It allows watching over the animal regardless to presence/absence of daylight without disturbing its circadian rhythms. The plastic box with the animal inside was positioned 30 cm from the antenna of the bioradar (Fig. 1).

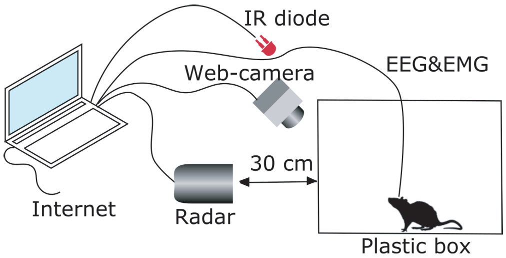

Figure 1: Scheme of the experiment.

As ground truth for discrimination of wakefulness and sleep we used a classical combination of EEG and EMG signals. For EEG recording the rat was chronically implanted epidurally with stainless-steel screws over the frontal and parietal cortex; reference electrode was located over the cerebellum. EMG electrode was placed in the neck muscles. All the signals were led to a multi-channel differential amplifier (ADInstruments, Australia) via a swivel contact (Moog Inc., USA). Experiments were conducted at the Institute of Higher Nervous Activity and Neurophysiology of Russian academy of science (Moscow, Russia). In the experiments a female Wistar rat was examined. Signals from contact sensors, web-camera and the bioradar were recorded simultaneously. The duration of the record was 24 hours. To synchronize the respiration pattern records for contact and non-contact methods synchronizing movement artifact was used: the operator swing the palm in front of the bioradar antenna and web-camera when starting the experiment.

3. BIORADAR DATA PROCESSING

The bioradar record consists of 2 signals (I and Q quadratures). Changing of distance between the animal and the radar alters an amplitude of the bioradar signal. Thus, it is impossible to choose between these two channels for analysis during the whole day record. To solve this problem we

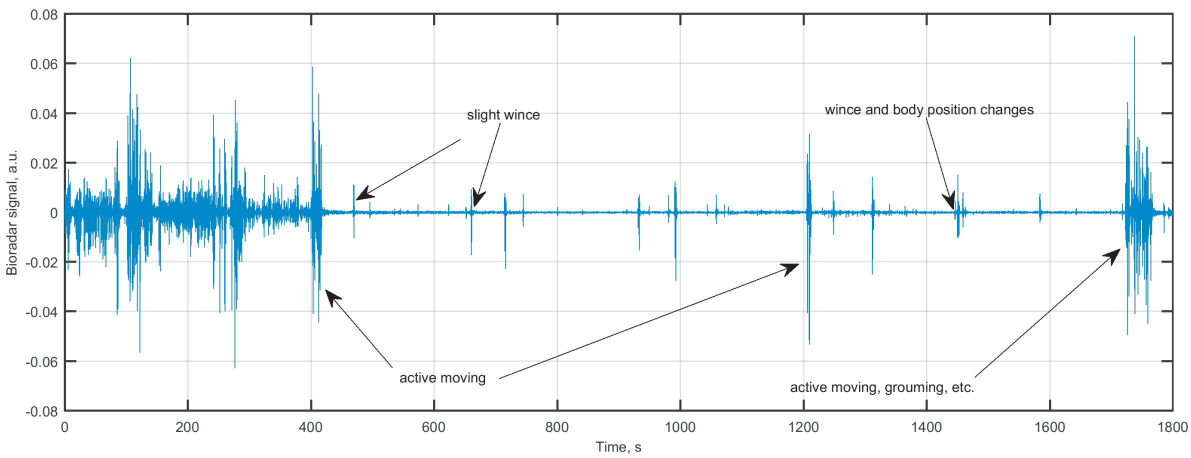

Figure 2: Raw bioradar signal with different types of rats locomotor activity.

choose the signal with the highest amplitude for each period free from the movement artifacts. To do so first of all movement artifacts need to be detected in the bioradar record. The time and frequency parameters of these artifacts depends greatly on the type of the activity (Fig. 2).

Moreover the amplitude of the artifact is a function of a distance between the rat and the bioradar, that is why the artifact removal algorithm should be adaptive. Fig. 3 shows how the amplitude of the bioradar signal changes when the rat moves from the back to the front wall of the box.

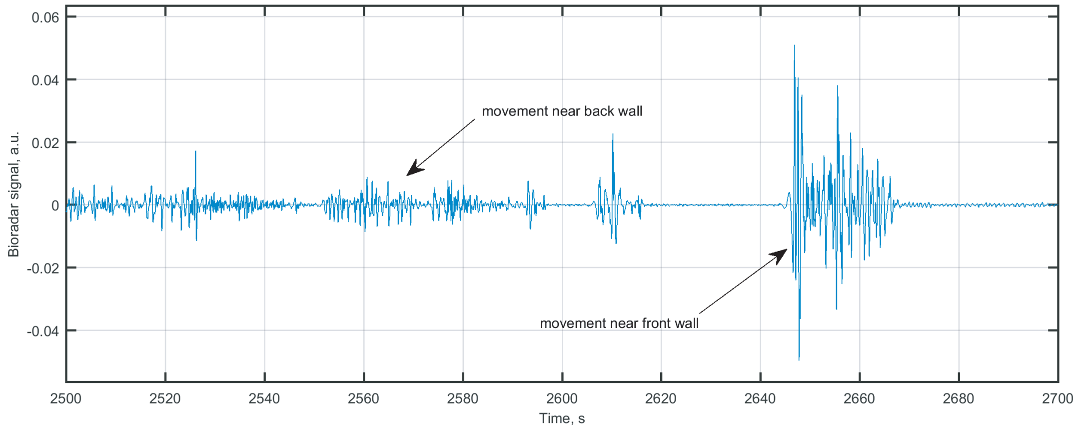

Figure 3: Alteration of bioaradar signal amplitude caused by distance changes.

Bioradar data processing has been made as follows.

- The bioradar signals were filtered with the 4th order Butterworth high-pass filter with cut-off frequency of 0.05 Hz to suppress a baseline drift.
- Artifacts intervals were detected by the analysis of maximum signal energy. A moving window of 4 seconds with the step of 1 second was used for its computing. If this parameter was 10 times higher than the mean value for the test record made before the experiment, the interval assumed to be an artifact. Fig. 4 illustrates the proposed algorithm performance. In Fig. 4 zero-level on the lower panel corresponds to the periods without artifacts and level of “1” — to the artifacts. To estimate the accuracy of the artifact detection algorithm 3 hours of the record was manually labeled as “0” and “1” using as a ground truth the record from the web-camera. The accuracy of the artifact detection is estimated to be 88%. The errors in

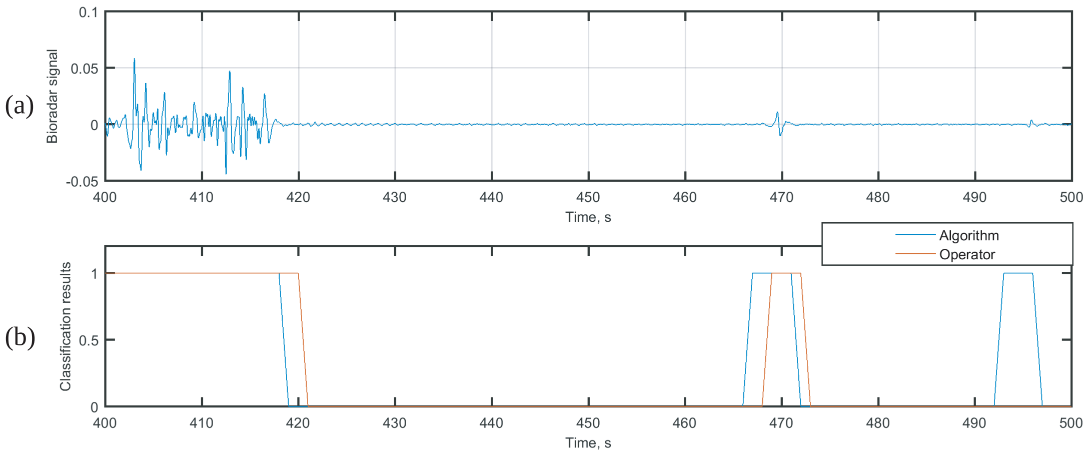

Figure 4: (a) Fragment of bioradar signal. (b) Artifacts periods detected by the algorithm (blue line) and by operator (red line).

classification is caused mainly by slight winces that not always can be detected on the video (one such wince is presented at the end of the bioradar signal in Fig. 4 and faults in precise estimation of beginning and ending of the artifact on the video record.

For periods of bioradar signal without artifacts a low-pass Butterworth filter with a cut-off frequency of 5.0 Hz was applied to clear respiration patterns of rats from noise and clutter. After filtration the following features were extracted for each 4 seconds epoch:

- the peak frequency of the spectrum;
- the energy of the signal;
- the entropy of the signal;
- the spectral powers in the respiration band $[0.8, 1.8]$ Hz.

This features were used to discriminate wakefulness (W) from the sleep (S) state while analyzing bioradar signal. Data processing and classification were done utilizing MATLAB 2016b.

4. RESULTS

To discriminate W/S events in bioaradar records we tried different classification techniques realized in Classification Learner in MATLAB, and chose four classifiers with best performance: Boosted trees, RUSBoosted trees, Bagged trees, and Medium Gausian SVM [11]. To evaluate the implemented classifiers and prevent overfitting, we apply the cross validation k-folds technique with $k = 5$. As it can be seen form Tables 1–4, that presents confusion matrixes, accuracy, and Cohen's kappa coefficients, all proposed classifiers showed similar results. The best accuracy of 82% and Cohen's kappa of 0.58 showed Boosted trees classifier, which ensembles AdaBoost method with Decision Tree learners.

Table 1: Boosted trees.

		Predicted class	
		Wake	Sleep
True class	Wake	4451	2318
	Sleep	1404	13379
Accuracy, %		82.7	
Cohen's kappa		0.584	

Table 2: RUSBoosted trees.

		Predicted class	
		Wake	Sleep
True class	Wake	4481	2088
	Sleep	1728	13055
Accuracy, %		82.3	
Cohen's kappa		0.574	

Table 3: Bagged trees.

		Predicted class	
		Wake	Sleep
True class	Wake	4397	2372
	Sleep	1723	13060
Accuracy, %		81.0	
Cohen's kappa		0.547	

Table 4: SVM Medium.

		Predicted class	
		Wake	Sleep
True class	Wake	3459	3310
	Sleep	888	13895
Accuracy, %		80.5	
Cohen's kappa		0.500	

5. CONCLUSION

In this preliminary work, we demonstrate that the continuous wave bioradar can be used as an alternative to standard EEG/EMG techniques for remote prolonged monitoring of laboratory animals daily activity. The proposed method is able to classify epochs to wake/sleep stages with accuracy of 82.7% and Cohen's kappa of 0.584. Some limitations of the study should be noted. The dataset is small and contains data for a single animal only. Thus, the results should be accepted with caution.

The future activity will consider expanding the data. In addition, we are planning to improve the classifier performance by extension of number of classification parameters so to be able to perform

3-stages classification (wakefulness/NREM/REM). The work might contribute to the development noncontact system for long-term monitoring of animals, which might be helpful for sleep medicine studies.

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