Estimation of Rat's Sleep-Wake Cycle Using a Bio-radar

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Abstract **– This paper presents a method for non-contact estimation of rats sleep-wake stages based on the analysis of a bioradar signal. The method was validated utilizing data of the rat, which underwent sleep study in a laboratory of Neuroontogenesis of Institute of Higher Nervous Activity and Neurophysiology of RAS. For the animal a bioradar signal was recorded during 48 hours. We achieved Cohen's kappa of 0.44 for the wake-NREM-REM classification and 0.70 for the sleep-wakefulness classification. The results might be used while creating new non-contact devices for laboratory animals sleep monitoring for diagnosis and studying sleep and sleep relative disorders.**

1 INTRODUCTION

At present the standard experimental procedure for monitoring sleep-wake cycles in rodents involves recording of electroencephalogram (EEG) and electromiogram (EMG) by means of implanted electrodes. Apparently, a necessity of preliminary surgery for electrodes implantation is a huge drawback of this technique, because it is a time and labor consuming task involving ethical issues. Thus the development of new non-contact methods for remote monitoring of laboratory animals vital signs is an up-to-date task. Such devices will not have an impact on measured parameters as standard contact or implanted sensors do. As a result, the informative value of the registered data would increase.

Today for non-contact estimation of laboratory animals vital signs may be used special home-cage systems [1, 2] and video-tracking devices [3]. The main drawback of such systems is their applicability for a specific type of the animal only. Furthermore, video-tracking devises are extremely sensitive to the light conditions and cannot be used in case of optically nontransparent shelters presence, while usage of additional source of light will results in disturbing of animal daily rhythms. There are systems with pressure sensors [4], electrodes [5], light sources and optical sensors [6] embedded into the cage floor or walls, but all of them are also suitable only for animals similar in size.

At present paper we propose to use short range radars (bioradars) for remote non-contact monitoring of sleep-wake cycles of laboratory animals (specifically rats). Bioradiolocation is the method for remote non-contact studying of biological objects vital signs. Bioradars are currently used for detecting of persons behind walls during counter-terrorist or rescue operation while searching for victims under the building rubble. Moreover bioradars may be used in sleep medicine [7,8], and fall detection for elderly [9].

Bioradars can monitor respiration and locomotor activity not only of humans, but also of animals. However, the majority of bioradar experiments describes respiration variability monitoring only on anesthetized animals [10]. The duration of experiments in such studies is also quite short (several hours or even minutes).

This study is a continuation of our previous work on animal sleep stage classification based on bioradar signals [11]. Here we propose the bioradar assisted technique which is suitable for long-term non-contact monitoring sleep-wake cycles of animals (e.g. for several days or weeks).

2 APPARATUS AND METHODS

The proposed in this paper method was validated utilizing experimental data of a female Wistar rat, which underwent sleep study in a laboratory of Neuroontogenesis of Institute of Higher Nervous Activity and Neurophysiology of RAS. The photo and scheme of the experimental setup are presented in Fig. 1 and 2.

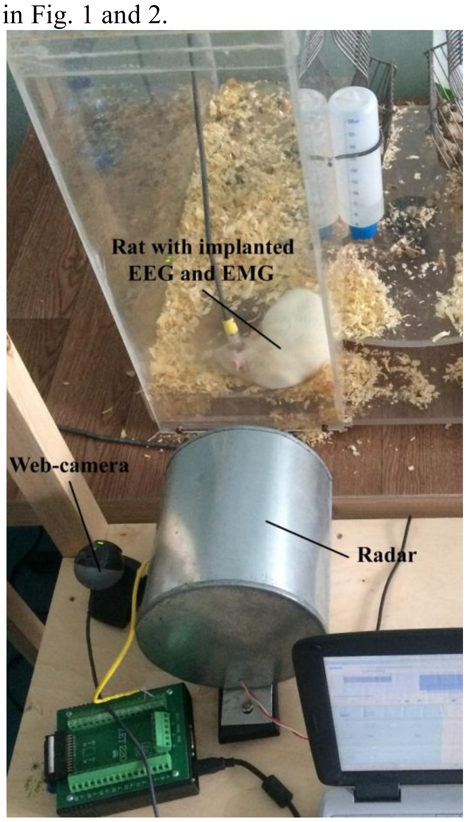

Fig. 1 Photo of the experiment

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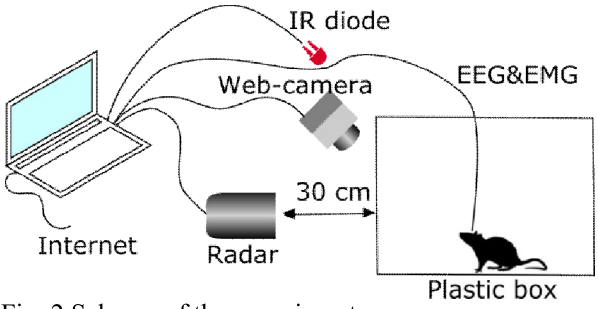

Fig. 2 Scheme of the experiment.

During the experiments bioradar data were recorded simultaneously with a classical combination of electroencephalogram (EEG), electromiogram(EMG), and video data, which are needed for experienced biologist to classify the sleep stages of the animal. 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).

To have a video record of the experimental scene a web-camera was used. Furthermore, we used an infrared diode to light up the experimental scene, which allows observing the animal regardless to presence/absence of daylight without disturbing its circadian rhythms. Wakefulness (W), rapid eye movement sleep (REM) and slow wave sleep or non-REM were visually scored in 1 s epochs by an experienced biologist using standard EEG and EMG criteria.

As in our previous work for the present study we used a monochromatic bioradar with a probing frequency of 7 GHz designed at Remote Sensing Laboratory of Bauman Moscow State Technical University [12]. It has a single transceiving cylinder antenna. The bioradar characteristics are listed in Table I.

Table I BioRASCAN-7 technical characteristics

RF output, mW	<3
Gain constant, dB	20
Detecting signals band, Hz	0.03-5.00
Dynamic range of the detecting	60
Size of antenna block, mm	370x150x150

During the experiment the animal was placed into the plastic box positioned 30 cm from the antenna of the bioradar (Fig. 2). For all channels the data were recorded for 48 hours nonstop.

3 DATA PROCESSING

3.1 Data preprocessing

As the bioradar used in the experiments has a quadrature receiver, the recorded signal consisted of two data patterns (I and Q quadratures). We need to preprocess them prior to extracting the features, which would be used in constructing a sleep stages classifier. This preprocessing step is essential because the bioradar signal amplitude depends greatly on the distance to the object, which is changing while the animal is moving inside the box.

The bioaradar signal preprocessing algorithm has been designed utilizing MATLAB and can be described as follows:

1) The baseline trend was suppressed by using a highpass Butterworth filter with a cut-off frequency of 0.5 Hz.
2) Synchronization of bioradar data with EMG, EEG and video records were performed by using synchronization artifact.
3) The bioradar record was divided into intervals free from movement artifacts utilizing the algorithm proposed in [13].
4) For each time interval free from the movement artifacts we chose the quadrature with the highest energy.
5) To extract respiration pattern of the animal from the bioradar signal we used a lowpass Butterworth filter with a cut-off frequency of 5.0 Hz, which clears respiration patterns of rats from noise and clutter.
6) For each free from movement artifacts period peaks and troughs were detected as a turning points. For better performance we used two additional threshold parameters: minimum peak height is equal to a 0.25 level of the average values of the local peaks for the analysed interval, and minimum distance between the peaks is 0.5 s, which is twice less than average respiration period of rats.

3.2 Features extraction

The following features were computed directly from 1 s epochs:

1) the peak frequency of the spectrum;
2) the energy of the signal;
3) the entropy of the signal;
4) the spectral power in the respiration band [0.8,1.8] Hz.
5) the spectral power in the very low frequency band between 0.05 and 0.25 Hz, the low frequency band between 0.25 and 0.80 Hz;
6) maximum, minimum values, means and standard deviations of peaks, troughs, inter-peak and inter-troughs intervals.

3.3 Classification

To discriminate W, REM and non-REM in bioaradar records we tested different classification techniques realized in ClassificationLearner in MATLAB, and chose two classifiers with best performance: Bagged trees, and RUSBoosted trees [14].

As a test dataset we used the data of the first 24 hours, and the data of the second day of the experiment was used to train classifier. To evaluate the implemented classifiers and prevent overfitting, we apply the holdout validation technique with held out percent of 25 %.

Results of epochs classification by an experienced biologist were used as a ground truth.

4 RESULTS

The results of the designed classifiers performance for the test dataset can be seen from Tables II-V. Tables II-III presents confusion matrixes, accuracy, and Cohen's kappa coefficients for sleep/wake classification, and Tables IV-V show the same parameters for W/NREM/REM classification.

We used Cohen's kappa coefficient to estimate an inter-rater agreement, because it is suitable for an imbalanced cases, which is a sleep stage classification.

Table II

		Bagged trees	
		Wake	Sleep
True class	Wake	25440	5717
	Sleep	6334	48910
Accuracy, %		86.05	
Cohen's kappa, %		69.88	

Table III

		RUSBoosted trees	
		Wake	Sleep
True class	Wake	25359	5798
	Sleep	6701	48543
Accuracy, %		85.53	
Cohen's kappa, %		68.83	

Table IV

		Bagged trees		
		W	non-REM	REM
True class	W	25359	5698	19
	non-REM	5219	42659	35
	REM	1115	6089	127
Accuracy, %		78.96		
Cohen's kappa, %		59.37		

Both proposed classifiers showed similarly good results for sleep/wake classification: the accuracy of 0.86, 0.85 and Cohen's kappa of 0.70, 0.69 for Bagged trees and RUSBoosted trees classifiers, respectively. However, for 3 stage classification the results were not so accurate: the accuracy of 0.79, 0.65 and Cohen's kappa of 0.59, 0.45 for Bagged trees and RUSBoosted trees classifiers, respectively.

Table V

		RUSBoosted trees		
		W	non-REM	REM
True class	W	25359	3104	2694
	non-REM	5732	26651	15530
	REM	969	2456	3906
Accuracy, %		64.71		
Cohen's kappa, %		44.67		

As it can be seen from Tables IV and V the Bagged trees classifier is better at prediction of non-REM stage comparing to RUSBoosted classifier, but the latter performs better at REM sleep classification.

5 CONCLUSION

In this paper we present a new method for non-contact estimation of rats sleep-wake stages based on the analysis of bioradar signal. The proposed method allows to perform sleep/wake classification with classify Cohen's kappa of 0.44 for the wake-NREM-REM classification and 0.70 for the sleep-wakefulness classification.

However the achieved results should be accepted with caution, because the classifiers were using data from a single rat.

The future activity will consider enriching the dataset. Moreover, we are planning to improve the classifier performance by using additional heuristics considering the probabilities of each sleep stage onset.

The results might be used while creating new non-contact devices for laboratory animals sleep monitoring for diagnosis and studying sleep disorders and sleep relative disorders.

Acknowledgments

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