A novel approach in automatic estimation of rats' loco-motor activity

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ABSTRACT

The paper contains feasibility study of a method for bioradar monitoring of small laboratory animals loco-motor activity improved by using a corner reflector. It presents results of mathematical simulation of bioradar signal reflection from the animal with the help of finite-difference time-domain method. It was proved both by theoretical and experimental results that a corner reflector usage during monitoring of small laboratory animals loco-motor activity improved the effectiveness of the method by reducing the dependency of the power flux density level from the distance between antennas block and the object.

Keywords: Bioradiolocation, bioradar, FDTD modeling, loco-motor activity, laboratory animals

1. INTRODUCTION

Nowadays rodents remain one of the most frequently used experimental models in pharmacology and zoo-psychology while studying new medicines and toxic agents. For studying animals psychology scientists use observation method in a variety of behavioral experiments, which allows detecting changes in animals' behavior. The most commonly used tests are open field, forced swim, dark/light tests, as well as tests in which mazes of various shapes and configurations are used.

However, while testing drugs and toxic substances invasive methods are used for measuring physiological parameters of laboratory animals to assess their dynamics. The researcher in this case estimates animals' loco-motor activity visually that is similar with the observation method for behavioral tests of animals. It is possible to reduce the workload on the operator by applying of automatic methods, which estimates loco-motor activity of animal using specially designed video-tracking system, such as Ethovision[1]. The main drawbacks of such type of system are relatively large volume of recorded information and the fact that further analysis of the received video signal requires rather complex processing algorithms. Moreover, video-tracking systems cannot be used while applying optically opaque mazes.

There are devices based on different physical principles, which can be used for automated monitoring of motor activity parameters of laboratory animals. Some of them contain pressure sensors mounted in the cage floor, which allows estimating of the animal movement in the cage[2]. Others use light sources and optical sensors integrated in the cage walls[3]. Also for similar purposes electromagnetic radiation is proposed to be used[4].

The main drawback of all these devices is a manufacturing complexity of the cage, in which the animal is placed during the experiment. Furthermore, the cages in such cases are designed for a certain type of laboratory animal which specific morphometric features need to be taken into account. That is why generally a loco-motor activity of the animals is estimated by a researcher visually, which may affect the quality of the received information.

Devises based on the method of bioradiolocation[5,6] are free of the drawbacks listed above. They measure a phase shift of the radar signal reflected from the biological object, which is caused by body surface displacements. This method does not require designing of special cages constructions and may be used with plastic containers in which animals are usually kept in or with optically opaque mazes. Another advantage of bioradar sensors in solving overstated problem is the possibility of direct integral automated evaluation of animals' loco-motor activity for a prolonged period. The size of the data file is much smaller comparing with the video tracking system file that allows researcher to record radar data continuously for several days or more. Fig.1 presents a fragment of the bioradar-recorded signal. Periods of steady state and movement activity can be easily recognized only by using simple threshold method. In 2009-2010 in Remote Sensing Laboratory (Bauman Moscow State Technical University) preliminary experiments were carried out, which showed that different types or rats loco-motor activity may be distinguished by means of bioradar[5].

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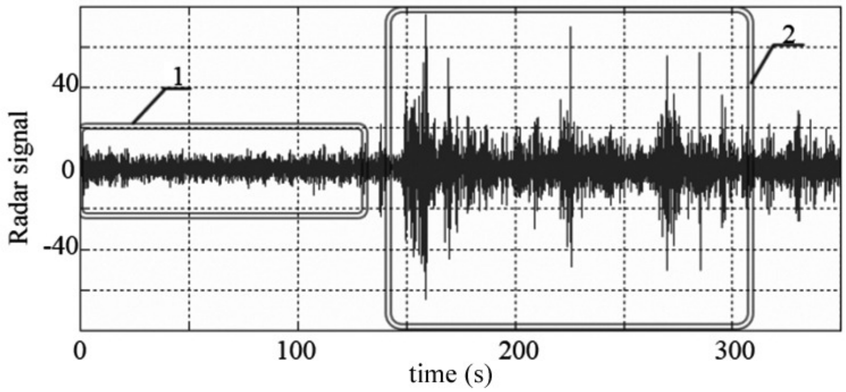


Figure 1. Radar signal reflected from an animal (1 – steady state, 2 – physical activity).

However, these experiments also showed that the power of the received signal depends greatly on the distance between antennas block and the object, which significantly decrease the accuracy of threshold method for movement intensity estimation. In classic radiolocation for elimination of this factor corner reflectors (CR) are used. For studying of a CR usage effectiveness while rats movement activity monitoring by means of a bioradar we carried out a mathematical simulation and experimental testing of this process for cases with and without CR. Paragraphs 2 and 3 present results of mathematical simulation and experiments respectively.

2. MATHEMATICAL MODEL OF ELECTROMAGNETIC WAVE INTERACTION WITH AN ANIMALS' BODY

FDTD-base modeling software[7] was used for 3D simulating of the electromagnetic wave propagation process in the context of solving problem. A 3D CAD model was used as a mathematical model of a rat (Fig. 2). This model imitates only the shape of an animals' body and does not take into account its internal structure. The material of the 3D rat model had following dielectrically properties: conductivity is 2.8 S/m and relative permittivity is 46. These values correspond to properties of a muscle tissue at 3.0 GHz probing frequency[8]. Such simplified representation of the detecting object can significantly reduce the effort required while creating an anatomically realistic model; however, it does not affect the results of modeling significantly.

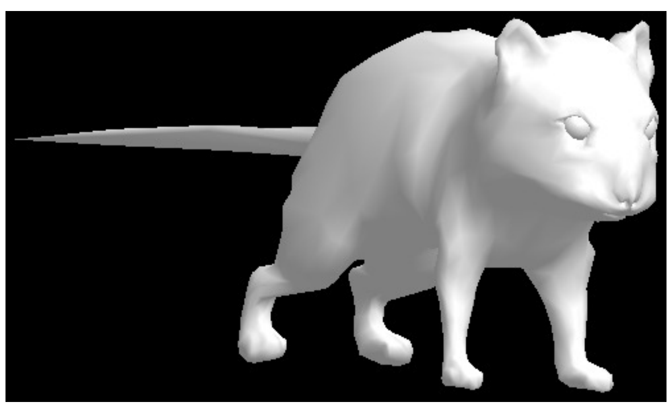
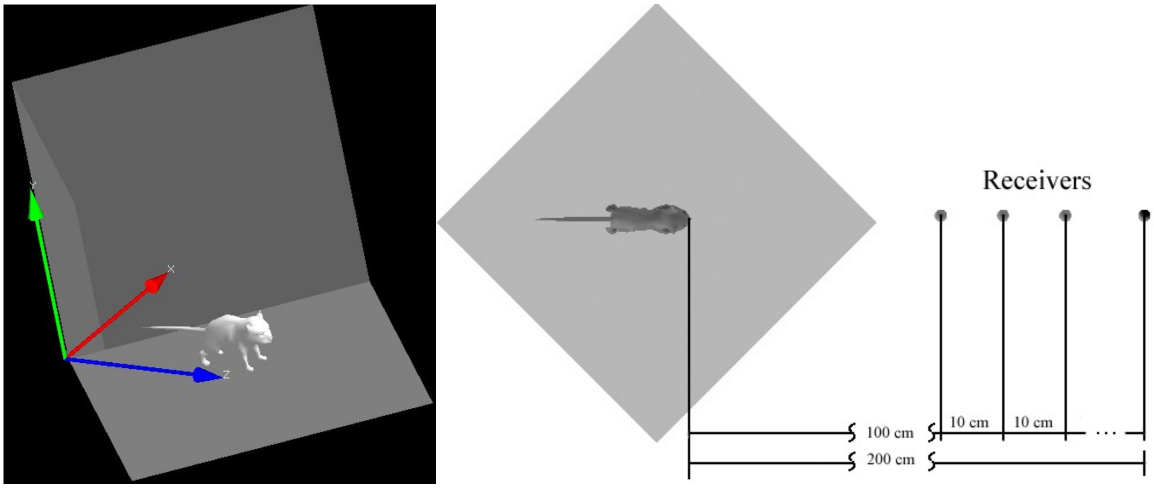


Figure 2. A 3D model of an animal.

We carried out simulation for two cases: with and without CR. A CR was formed by three orthogonal plates 70x70x70 cm each between them a model of a rat was placed (Fig. 3a). In simulation with CR the distance from the center of the model of a rat to CR vertex was 0.3 m. The distance between the center of the rat model and receiving antenna along z-axis varied from 1.0 to 2.0 m with a step of 0.1 m, which was found out as the most suitable ranges while estimating of rats' loco-motor activity by means of a bioradar in practice. Parameters of the scattered electromagnetic field were calculated at 11 points imitating receivers (Fig. 3b).



(a) (b)

Figure 3. Mathematical model geometry with CR usage.

Probing signal frequency was set equal to 4.0 GHz, which corresponds to one of the probing frequencies of the bioradar used in the experiments. As a source type, an impinging plane wave of sinusoid type was set up. It propagates in the direction opposite to Z-axis in Fig. 3a. Fig. 4 presents the probing signal and its spectrum.

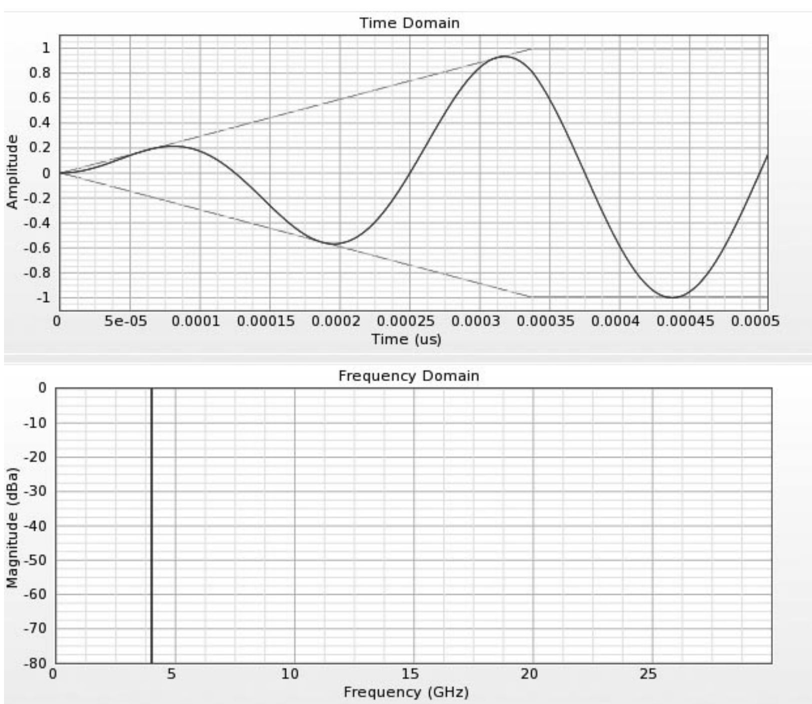


Figure 4. Probing signal and its spectrum.

We used a perfect electric conductor, which exhibits infinite electrical conductivity, as a CR material. Cell size was set in accordance with probing frequency of 4 GHz by the following equation:

$$l = \frac{c}{2f} = \frac{3 \cdot 10^8 \ m/s}{2 \cdot 4 \ GHz} \approx 4 \ cm$$

where
c – electromagnetic wave propagation velocity in vacuum;
f - probing frequency.

A computational domain was a rectangular block of 188x200x470 cells, which is 0.75x0.80x1.88 m. Outer-boundaries were set to be absorbing. For each receiver we calculated y-directed vector of electric field $\dot{E}_y$. Results of calculation for real and imaginary components of $\dot{E}_y$ and its absolute values $\left|\dot{E}_y\right|$ for each receiver are presented in Table 1 and in Fig. 5.

Table 1. Amplitude of $\dot{E}_y$ for a range of distances between the animal and antennas.

Distance, m	Model with CR			Model without CR		
	$\mathrm{Re}(\dot{E}_y)$	$\mathrm{Im}(\dot{E}_y)$	$\lvert\dot{E}_y\rvert$	$\mathrm{Re}(\dot{E}_y)$	$\mathrm{Im}(\dot{E}_y)$	$\lvert\dot{E}_y\rvert$
	$\times 10^{-9}$, V/m			$\times 10^{-11}$, V/m		
1.0	1,32	-1,08	1,71	4,16	6,67	7,86
1.1	-1,59	-0,54	1,68	3,70	-5,76	6,85
1.2	0,33	1,66	1,69	-5,97	-0,70	6,02
1.3	1,35	-1,10	1,74	1,75	4,96	5,26
1.4	-1,63	-0,73	1,79	3,32	-3,31	4,68
1.5	0,01	1,79	1,79	-3,95	-1,39	4,18
1.6	1,64	-0,73	1,79	0,33	3,65	3,66
1.7	-1,28	-1,17	1,74	2,80	-1,58	3,21
1.8	-0,57	1,54	1,64	-2,26	-1,57	2,75
1.9	1,54	-0,07	1,54	-0,39	2,28	2,32
2.0	-0,60	-1,25	1,38	1,91	-0,56	1,99

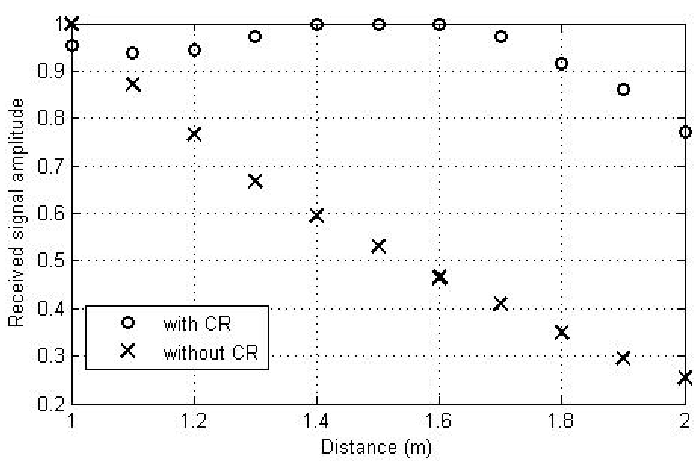


Figure 5. Probing signal and its spectrum.

As it is clearly seen from Table 1 that usage of CR results in two orders increasing of scattered $\left|\dot{E}_y\right|$ values compared with the case when CR was absent. To make the results of simulating with and without CR easier to compare Fig. 5 presents normalizes $\left|\dot{E}_y\right|$ values. These results confirm that using of CR allows decreasing received signal power dependency from the range to the object. In case when CR is present alteration of the distance between the animal and antennas from 1.0 to 2.0 m results in not higher than 12 % variation of received signal amplitude ($\left|\dot{E}_y\right|$). However, in case if CR is not used the same changes exceed 60 %.

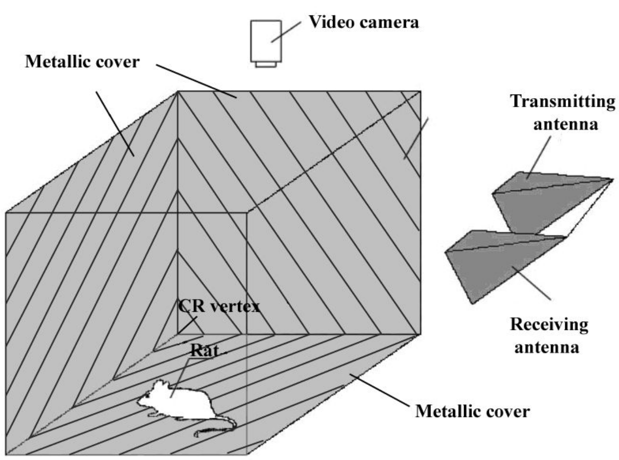
3. EXPERIMENTAL RESULTS

Multi-frequency radar with quadrature receiver designed at the Remote Sensing Laboratory was used in experiments with laboratory rats. The radar had following technical characteristics:

Number of frequencies	16
Sampling frequency	62.5 Hz
Operating frequency band	3.6 – 4.0 GHz
Distance space resolution	0.5 m
Recording signals band	0.03 – 5.00 Hz
Dynamic range of the recording signals	60 dB
Dimensions of antennas block	150×150×370mm

This radar was created for remote monitoring of movement activity, breathing and heartbeat of human. Nevertheless, it could be also used for tracking movement of small laboratory animals.

Sketch and photo of the experimental set up for estimation of animal's movement activity by means of radar are given in Fig 6a and 6b respectively. During experiments, the animal (Wistar rat) was placed into a box of 70x70x70 cm size with dielectric walls. Two walls and a floor of the box were covered with aluminum foil to form CR. Transmitting and receiving antennas of the radar were pointed to the box as Fig. 6b shows.



(a)

(b)

Figure 6. Scheme and photo of the experimental set up.

While conducting the experiments antennas were placed on a tripod in such way that the distance from it to the rat varied from 1.0 to 2.0 m in 0.1 m increment, which is equal to parameters used for mathematical simulation. We conduct two series of the experiments: with and without CR. During the experimental procedure, we need a rat to sit steady at exact distance from the antennas to compare received bioradar signal power for the same range as it was done in mathematical model. To prevent animal from moving it was placed into a plastic container, which is shown in Fig. 7.

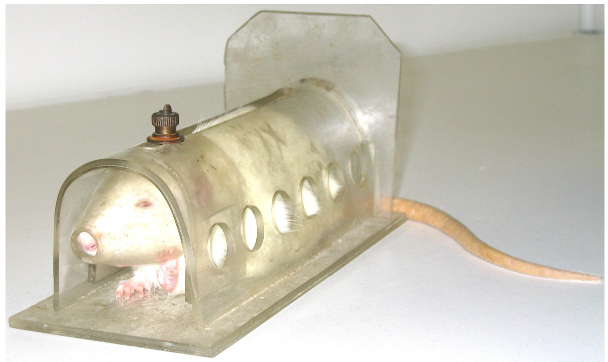
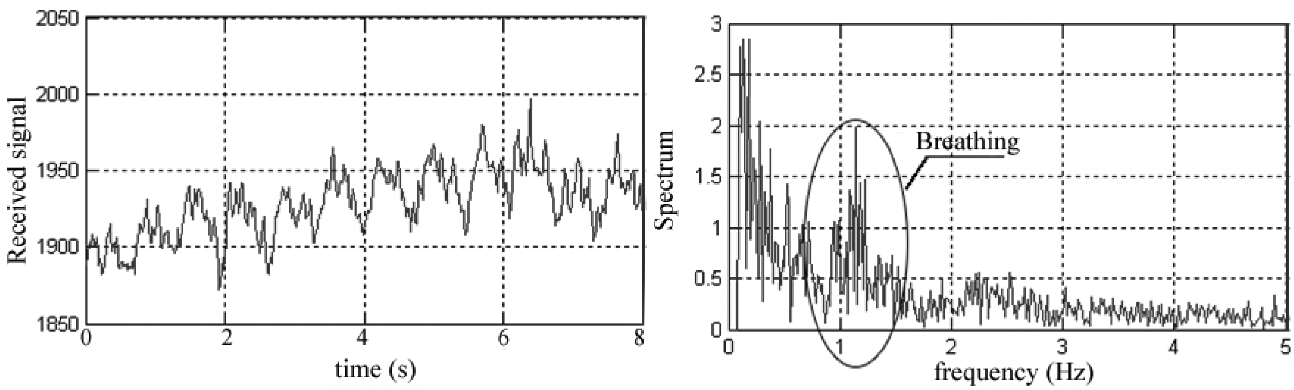


Figure 7. Rat in a plastic container.

It is worth to be mentioned that such relatively motionless state of the experimental animal allows estimating its' respiration frequency (Fig. 8), which may be useful if researcher is interested in non-contact monitoring of rats respiration dynamics.



(a) (b)

Figure 8. The recorded bioradar signal (a) and its spectrum (b).

Fig. 9 presents the results of the experiments with and without CR usage. The normalized power of the recorded bioradar signal reflected from the animal for each of the ranges listed above for both cases with and without of CR

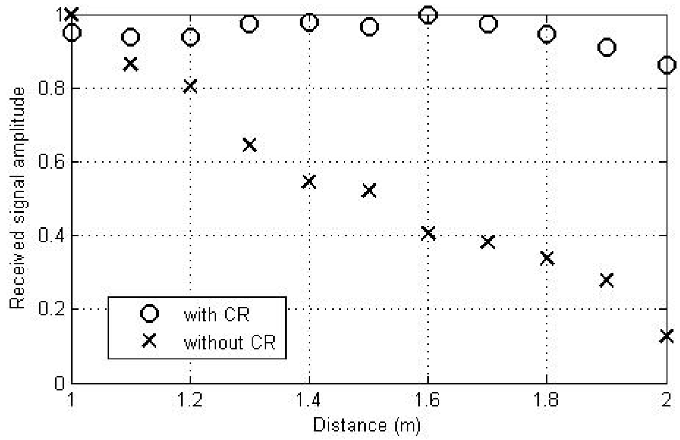


Figure 9. Amplitude of received bioradar signal vs. the distance between the animal and antennas.

4. CONCLUSION

Results of mathematical simulation proved that CR application leads to decrease of received signal power dependency from the range to the located object. In case when the animal is placed into the box of 0.7x0.7x0.7 m size received signal amplitude vary less than 12 %, whereas if CR is absent this value is more than 60 %.

Comparison of experimental and theoretical results showed that proposed mathematical model is adequate for observed phenomena simulation and CR usage may be proposed as an effective measure for eliminating of received signal power dependence from the range to the located object. In this case, bioradiolocation method may provide a prolonged accurate estimation of small laboratory animals' integral movement activity for pharmacology or zoo-psychology.

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