Detection of inhomogeneities in biological tissues using radio wave tomography

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Abstract. The paper shows the method for detecting and mapping inhomogeneities in biological tissues with using the radio-wave tomosynthesis. The method of radio-wave tomosynthesis allows calculating a three-dimensional distribution of permittivity in a studying space. The distribution gives the opportunity to determine tissue inhomogeneities, also their location and size. This method is suitable for dynamic observation of changes in education size due to harmlessness to humans. Unlike X-ray methods, for which regular doses of ionizing radiation contraindicated. Therefore, the development of non-invasive methods for the search for inhomogeneities in biological media based on radio-wave sounding is very relevant.

1. Introduction
Breast cancer - a malignant neoplasm in the breast. It takes first place in the structure of cancer incidence in women. According to the World Health Organization, it is the most common cancer among women worldwide, accounting for 16% of all cancer cases among women. In the fight against breast cancer an early diagnosis is important (I-II stage). Currently, ultrasound and X-ray methods are most commonly used to detect tumors in biological tissues. Each of the methods are not absolute and sufficient and have their drawbacks. For example, during x-ray mammography, there is always a small chance to produce the cancer due to excessive exposure. If the patient is pregnant, then it makes the situation more complicated. Also, mammography is an expensive type of screening and is recommended for countries with proper health infrastructure. An ultrasound sensing at the early stage is often ineffective. Cause the density of tumors is almost the same as the density of the background. Consequently, neoplasm detection methods are needed, which will improve the diagnosis of breast cancer and allow starting treatment as early as possible, thereby significantly increasing the chances of recovery. Radio wave methods are new and promising non-invasive methods for the search for neoplasms in biological tissues, due to their sensitivity to even small changes in the electrophysical parameters of the environment and, compared to X-ray studies, have a lower average radiation power and are therefore safe for patients. With the appearance of neoplasms, fluid and blood accumulate in them, which entails a change in the dielectric constant of this formation [1, 2]. A change in the dielectric constant can be identified using radio wave tomography [3, 4]. Due to its harmlessness to humans, these methods are suitable for continuous monitoring of changes in the size of the formation, unlike x-ray methods, for which regular doses of ionizing radiation are contraindicated. Therefore, the development of non-invasive methods for the search for heterogeneities of biological media based on radio wave sounding, which allow to detect pathological formations, is currently very relevant.
2. Experiments on the detection of inhomogeneities in the biological medium

The article explores the possibility of obtaining information about the inhomogeneities contained in biological media during flat and spherical scanning. Different types of scans are used depending on the application. Hemispheric scanning can be used for radio wave mammography. It is for this direction that these studies are conducted. For flat scanning, the radio wave tomosynthesis method based on the Stolt method was used [3, 4]. In this case, measurements are made in the frequency domain using the fast Fourier transform. This provides a three-dimensional tomogram of the investigated medium. However, it is necessary to know the dielectric constant of the background medium. Dielectric permittivity measurement is possible by several methods [5, 6]. In previous works, the authors proposed the measurement of the electrophysical properties of the medium using the coaxial cell method. This method has good accuracy; measurements are carried out in a wide frequency band. It is possible to carry out measurements for liquid, bulk and viscous materials [7].

During the experiment, a two-coordinate scanner was used, which provided the movement of the measuring head. This head contained an ultra-wideband antenna that was connected to a Caban R140 vector reflectometer. After modeling, it was established, and also taking into account the properties of the antenna, the optimal range for sounding 2-8 GHz was chosen. Figure 1 shows a schematic representation of an experiment and its photograph.

As inhomogeneities, metal and plastic balls filled with saline were used. The radius of the balls was 0.65 cm. The balls were placed on each other at a distance of 3 cm. Ghee was used as a background biological medium, which is close to human in its electrodynamic properties.

After the experiment, images of artificial heterogeneities in the biological medium were obtained. Figure 2 shows the experimental results. After processing the obtained data, a three-dimensional tomogram of inhomogeneities in pork fat was constructed [7].

The experiment confirmed the correctness of the ideas. It was decided to conduct an experiment in a spherical coordinate system, since the female breast has a shape close to hemispherical and, accordingly, the scanning device must take this characteristic into account.

For image acquisition, a transceiver antenna was used over the hemisphere. The transmitting antenna emits a signal, which, being reflected from heterogeneity, is recorded by the receiving antenna. You can use both bistatic and monostatic sounding schemes. Knowing the time during which the wave travels from the antenna and back, as well as the dielectric constant of the medium in which the object is located, it is possible to find the distance to the object that determines the radius of the sphere where the object can be located. The center of the sphere is located at the location of the antenna. Having probed the studied area from different angles, one can obtain a set of spheres, at the intersection of which it is possible to determine the position of the heterogeneity in space. When solving the inverse problem, the space is divided into small cubes, each of which is an element of a three-dimensional array. The array shows the distribution of the dielectric constant in the study area, which allows you to select the desired...
slice and see the distribution of the dielectric constant in this slice. For experimental verification of the proposed method, a spherical scanner was used (Figure 3), which allows scanning in the upper hemisphere.

A “Caban R40” vector reflectometer was mounted on the scanner frame, which sends a signal to a compact ultra-wideband antenna, which was developed at the Department of Radiophysics. The antenna is receiving and radiating. The object was located on a rotating table. To construct a three-dimensional radio tomogram, we used the method of synthesizing apertures – moving the antenna around the object under study. Figure 4 shows the position of the antenna, i.e. signal recording points.

This allows you to set the number of angles, but increases the scanning time with large numbers of angles. Using a plurality of statically located antennas, instead of a single moving antenna, it is possible to significantly reduce the scanning time, but limits the number of angles. For scanning, the vector analyzer applied a radiated signal to the ultra-wideband antenna in the frequency range from 2 to 8 GHz. During the experiment, plastic balls with a diameter of 10 mm filled with saline were used. As in the previous experiment, the balls were in pig fat. As a result of scanning and solving the problem by the method of radio wave tomosynthesis, a three-dimensional data array was obtained, with which you can determine the size and position of the balls in the fat. Figure 5 shows one of the slices of the three-dimensional radio tomogram, where you can determine the position, shape and size of inhomogeneities.

**Figure 2.** The results of a flat scan (a - slice on the surface, b - slice in the plane of inhomogeneities, c - three-dimensional tomogram of the object under study).
Figure 3. Spherical scanner.

Figure 4. Antenna positions.

Figure 5. Radiotomography of test objects calculated using experimental data.
3. Conclusion
This paper presents a method for detecting and mapping inhomogeneities in biological media using the radio wave method. The proposed method of radio wave tomosynthesis allows you to calculate the three-dimensional distribution of electrophysical characteristics (dielectric constant) of the investigated space and, thereby, detect tissue inhomogeneities and determine their position, shape and size.

The results obtained during the experiments allow us to estimate the resolution of at least 1 cm when used for sensing the frequency range of 2-8 GHz.

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References
[1] Lazebnik M, Popovic D, McCartney L, Watkins C, Lindstrom M, Harter J, Sewall S, Ogilvie T, Magliocco A, Breslin T, Temple W, Mew D, Booske J, Okoniewski M and Hagness S 2007 Phys. Med. Biol. 52 6093–115
[2] Lazebnik M, Madsen E, Frank G and Hagness S 2005 Phys. Med. Biol. 50 4245–58
[3] Shipilov S E, Satarov R N, Fedyanin I S, Balzovsky E V and Yakubov V P 2017 J. Phys.: Conf. Ser. 881 012015
[4] Khmelev V L, Satarov R N and Zavyalova K V 2018 IOP Conf. Ser.: Mater. Sci. Eng. 363 012035
[5] Gorriti A G and Slob E C 2005 IEEE TGRS 43 2051–57
[6] Baker-Jarvis J, Vanzura E J and Kissick W A 1990 IEEE Trans. Microw. Theory Tech. 38 1096–103
[7] Shipilov S E, Eremeev A I, Balzovsky E V and Yurchenko E 2018 MATEC Web Conf. 155 01025–31