

Computer model for acquisition, processing, analysis and visualization of measurement data by electrical impedance tomography

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Abstract. In this article, a computer model for the collection, processing, analysis and visualization of measurement data by the method of electrical impedance tomography has been developed. The essence of the work performed is to build a computer model of the phantom, electrodes, conductive medium and inhomogeneities in the COMSOL Multiphysics environment to study the conductivity of objects in order to reduce the error in determining the size of the inhomogeneity in the reconstructed image. The study is performed by placing an inhomogeneity phantom in the conductive region. Based on the data obtained, a matrix of potential differences is constructed using the "near neighbor" algorithm. On its basis, in the GNU Octave environment, using the EIDORS package, a reconstruction of the conducted studies is obtained. With the help of the developed software that implements the method and algorithm for refining the boundaries, filtered images of reconstructions of the results of the studies are obtained. The use of this algorithm makes it possible to reduce the measurement error by a factor of 1.44.

1 Introduction

Electrical impedance tomography (EIT) is a method for visualizing the internal structures of an object under study, based on assessing the change in the conduction field in the plane of the electrode system when a low-amplitude high-frequency current is injected through the object (according to a given algorithm) while simultaneously recording the emerging potential differences. [1-5].

In the development of EIT hardware and software, the use of "phantoms" has become widespread. A phantom is a technical solution of an arbitrary design (proposed by a researcher) with electrodes located on the surface, which is connected to an EIT device. The phantom can be filled with various conductive and non-conductive media that mimic the internal structure of the object under study. Thus, the possibilities for modeling EIT research and evaluation of effectively proposed technical and algorithmic solutions are greatly expanded. The use of computer simulation makes it possible to increase the efficiency of the

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developed algorithms and the economic efficiency of scientific research. In this article, a computer model for collecting, processing, and analyzing data is developed, which makes it possible to conduct experimental model studies of a number of given inhomogeneities, for example, their spatial position in a phantom, geometric dimensions.

The proposed computer model allows organizing the EIT method by examining the conductivity of real objects in the program in order to reduce the error in determining the size of the inhomogeneity in the reconstructed image. The positioning of the inhomogeneity in the phantom is adequately reflected in the rendered image.

Given the above, the tasks that need to be solved in the course of this work are defined:

- develop a computer model of the phantom, electrodes, conductive medium and inhomogeneities to study the conductivity of objects using the EIT method;
- develop software that implements the developed algorithms;
- check the operation of the algorithm on computer models of inhomogeneities;
- consider the error in determining the size of the heterogeneity in the reconstructed image.

2 Development of a computer model of a phantom for collecting measurement data

To study the conductivity of real objects using the EIT method in the COMSOL Multiphysics® environment [6, 7], a phantom model was built with electrodes attached around the perimeter (shown in figure 1).

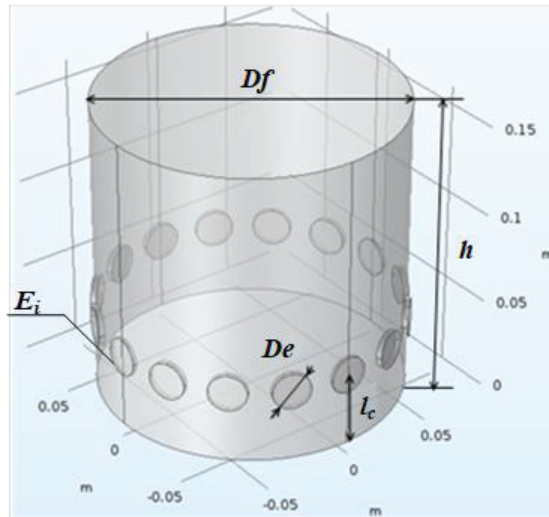


Fig. 1. Phantom model developed in COMSOL Multiphysics®.

The study type "Electric Currents" is selected to obtain voltage values at each electrode in COMSOL Multiphysics®. Using the Point Estimation tool, a table was created for each electrode with the corresponding voltage values. The numbering order of the electrodes is shown in figure 2.

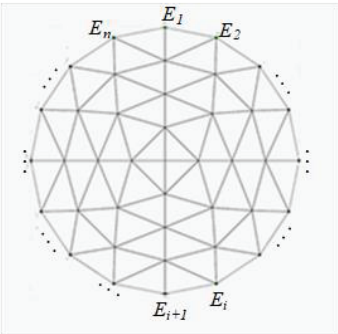


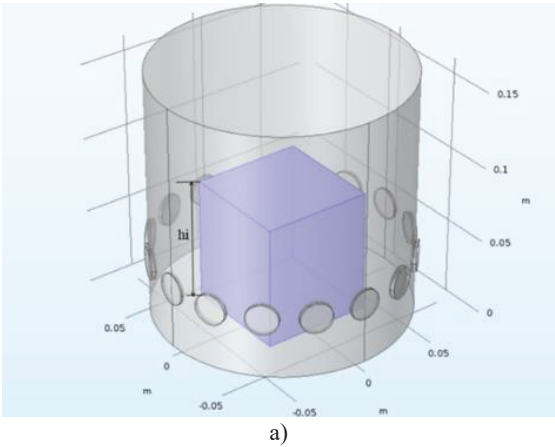
Fig. 2. Electrode Numbering Order (Ei) in COMSOL Multiphysics ®

Study parameters are presented in table 1.

Table 1. Heterogeneity Study Options in COMSOL Multiphysics® Software.

Df, mm	h, mm	De, mm	lc, mm	hi, mm	Frequen- cy of current, kHz	Current strength ,mA	Phantom material		Electrode material
160	160	20	40	80	100	5	0,9% NaCl		Copper
Section shape	Circle			Triangle			Rectangle		
									
Position	l=20mm			l=40mm			l=80mm		
S, mm	10	20	30	40	50	60	70	80	

The study is performed by placing an inhomogeneity phantom in the conductive region (shown in figure 3.3(a)). In this case, 6 different shapes of the heterogeneity section are used: “circle” (figure 3.3(b)), “rectangle” (figure 3.3(c)), “triangle” (figure 3.3(d)).



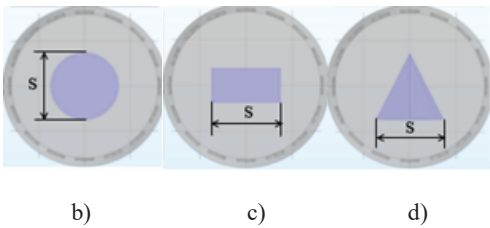


Fig. 3. Inhomogeneity in the phantom area (a), inhomogeneity with a cross section: b) circle, c) rectangle, d) triangle.

Three-dimensional computer models have been developed that were used to create inhomogeneities from polymer plastic using additive technologies.

The study uses electrode switching, which is the basis of the EIT conductance application. This application was developed in the COMSOL Multiphysics® environment. The application listing is written in java. The application interface is shown in figure 4 (a, b).

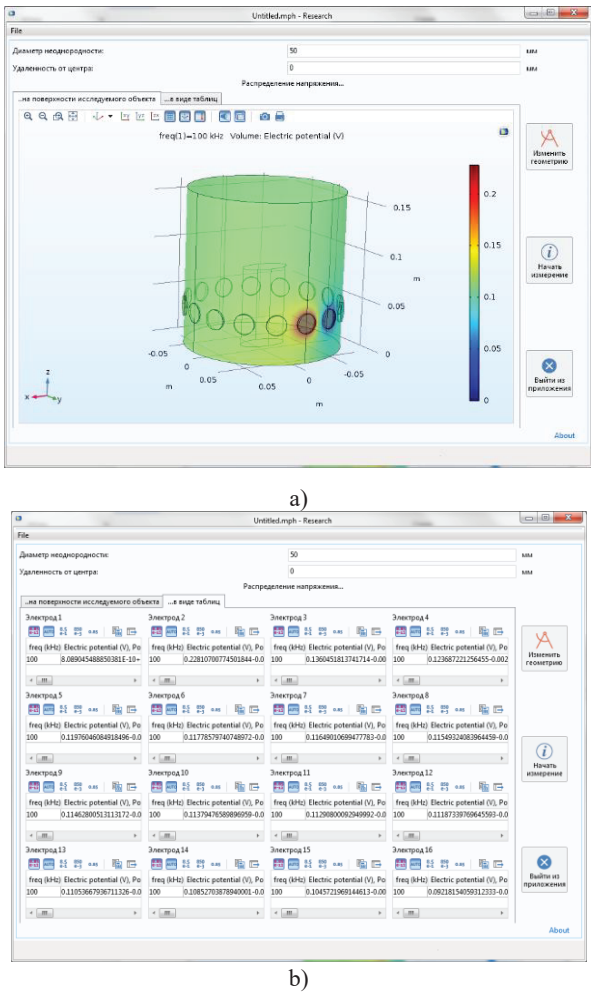


Fig. 4. Application workspace (a), application results (b) in COMSOL Multiphysics ®.

In the tab "Voltage distribution on the surface of the object under study" (Figure 4 (a)) on the three-dimensional model of the phantom, the result of the passage of current for each individual measurement is displayed.

The tab "Object stress distribution in the form of tables" (figure 4 (b)) displays 16 resulting tables with ϕ_i values. The number of each table corresponds to the number of the electrode on the phantom model. A separate table contains information on the value of F_{cs} , the value of the stress on the surface E_i for each of the 16 measurements taken. The study is carried out by clicking the "Start study" button

The application changes d and l - the corresponding fields are filled with the necessary values, then when you click the "Change geometry" button, the diameter of the inhomogeneity and its distance from the first injecting electrode change. The changes are displayed on the 3D model.

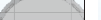
To obtain a reconstruction of the study by the EIT method, on the basis of the data obtained, a matrix [8] of potential differences was built using the "near neighbor" algorithm [9]. This algorithm calculates the potential difference $\Delta\phi_i$ between adjacent electrodes E_i , E_{i+1} . Thus, a matrix of potential differences $\Delta\phi_i$ is formed between adjacent electrodes for various configurations of the injection electrodes.

Based on the potential difference matrix obtained in the GNU Octave environment [10,11] using the EIDORS package [12], reconstructions of the studies were obtained. In addition, using the developed software that implements the method and algorithm for refining the boundaries, filtered images of reconstructions of the results of the studies were obtained, which are presented in table 3.

Table 3. Reconstructions resulting from the study.

	Circle							
Position	20 mm from the first injection electrode							
s, mm	10	s, mm	10	s, mm	10	s, mm	10	s, mm
Model								
Reconstruction								
	Circle							
Position	40 mm from the first injection electrode							
s, mm	10	20	30	40	50	60	70	80
Model								
Reconstruction								
	Circle							
Position	Phantom center							
s, mm	10	20	30	40	50	60	70	80
Model								
Reconstruction								

	Rectangle							
Position	20 mm from the first injection electrode							
s, mm	10	20	30	40	50	60	70	80
Model								
Reconstruction								
	Rectangle							
Position	40 mm from the first injection electrode							
s, mm	10	20	30	40	50	60	70	80
Model								
Reconstruction								
	Rectangle							
Position	Phantom center							
s, mm	10	20	30	40	50	60	70	80
Model								
Reconstruction								
	Triangle							
Position	20 mm from the first injection electrode							
s, mm	10	20	30	40	50	60	70	80
Model								
Reconstruction								
	Triangle							
Position	40 mm from the first injection electrode							
s, mm	10	20	30	40	50	60	70	80
Model								
Reconstruction								
	Triangle							
Position	Phantom center							
s, mm	10	20	30	40	50	60	70	80

Model								
Reconstruction								

Mathematical processing algorithms are applied to the obtained reconstructed images. The error in the results of determining d is calculated as follows:

$$\gamma = \left| \frac{d-d'}{d} \right| \cdot 100\%, \quad (1)$$

where γ - relative error of determination, d – is the diameter of the inhomogeneity used in the experiment, d' – inhomogeneity diameter determined by the calculation method.

The graph of the dependence of errors γ on d is shown in figure 9. The normalized error in determining γ_1 is indicated for the values of d' , obtained as a result of refinement of the boundaries of inhomogeneity. Similarly, the error in determining γ_2 is indicated for the values of d' , obtained as a result of calculating the dimensions of the inhomogeneity after binarization.

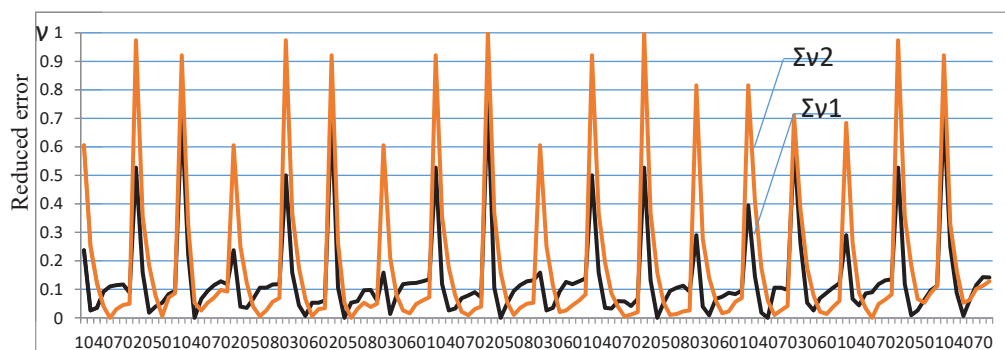


Fig. 9. Graph of determination errors d.

As a result of applying the method developed by the team of authors to refine the boundaries of inhomogeneity, the error in determining γ was reduced by 1.44 times.

3 Conclusion

As a result of the work performed, a computer model of the phantom, electrodes, conductive medium and inhomogeneities was built to study the conductivity of objects by the EIT method in the COMSOL Multiphysics environment. Based on the potential difference matrix obtained in the GNU Octave environment, using the EIDORS package, reconstructions of the studies were obtained. With the help of the developed software that implements the method and algorithm for refining the boundaries, filtered images of reconstructions of the results of the studies were obtained.

The use of computer simulation made it possible to increase the efficiency of the developed algorithms and the economic efficiency of scientific research through preliminary mathematical calculations on a computer model, and then the use of phantoms in practice.

It was found that the use of the developed algorithm for refining the boundaries of inhomogeneity reduces the error in determining the size of the inhomogeneity in the reconstructed image.

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