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IMPLEMENTATION OF MAGNETIC FIELD DATA TO IMPEDANCE TOMOGRAPHY

ABSTRACT *A new modification of the recent impedance tomography technique is presented in the paper. This new technique is used for non-invasivel imaging of the head tissues conductivity distribution and its changes. The algorithm based on one component of the measured magnetic flux density is introduced. The reconstructed conductivity image could be obtained through iterative solution of a corresponding matrix equation. According to the present algorithm, which uses one magnetic flux density component, numerical simulations were performed for two dimensional realistic human head model (consisting of the scalp, skull and brain) with the isotropic target conductivity distributions. By means of the algorithm, the reconstruction of skull and brain conductivity ratios could be figured out even under the condition that only one current is injected into the brain.*

Keywords: *impedance tomography, non-invasive imaging, head tissue conductivity, magnetic flux density, iterative solution matrix equation, algorithms, numerical simulation, models, imaging.*

1. INTRODUCTION

Recently the image reconstruction problem is a widely investigated problem with many applications in physical and biological sciences. The Electrical Impedance Tomography (EIT) can be used for the reconstruction process. The theoretical

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background and some applications of EIT are given in [1, 2]. In current EIT, the currents are applied through the electrodes attached to the surface of the object and the resulting voltages are measured using the same or additional electrodes. Then, a feasible reconstruction algorithm is used to estimate the distribution of electrical conductivity (respectively permittivity) within the object, based on the knowledge of the applied current patterns and the measured surface voltages. The current flow is determined by the impedance distribution within the object. Unfortunately, large changes in impedance at the interior of the object result in only small voltage changes on the surface of the object and the problem is ill-posed. Therefore, the spatial resolution of the conventional EIT is very limited and other methods as the Magnetic Resonance Electrical Impedance Tomography (MREIT) have been proposed to provide non-invasive high-resolution imaging of electrical impedance within an object [3, 4]. The image reconstruction of EIT is an inverse problem which is often presented as minimizing the suitable objective function $\Psi(\sigma)$ relative to σ. To minimize the objective function $\Psi(\sigma)$ a deterministic approach based on the Least Squares method can be used. Due to the ill-posed nature of the problem, the standard Tikhonov Regularization method was used to solve this inverse EIT problem

$$\min_\sigma \Psi(\sigma) = \min_\sigma \left[\frac{1}{2} \sum \left\| \mathbf{U}_M - \mathbf{U}_{FEM}(\sigma) \right\|^2 + \alpha \frac{1}{2} \left\| \mathbf{L}\sigma \right\|^2 \right], \tag{1}$$

where σ is the volume conductivity distribution vector in the object, $\mathbf{U}_\mathrm{M}$ is the vector of measured voltages at the boundary, and $\mathbf{U}_{\mathrm{F}EM}(\sigma)$ is the vector of calculated peripheral voltages relatively to σ, which can be obtained using FEM, α is a regularization parameter and $\mathbf{L}$ is a regularization matrix. The $\mathbf{U}_M$ can be obtained either by a direct voltage measurement or from the measurement of a magnetic flux density, which is induced by a corresponding current density. The components of the current density on elements we can obtain from the Biot-Savart´s law

$$\frac{\mu_0}{4\pi} \left[\frac{R_y \Delta V}{\mathrm{R}^3} \quad \frac{-R_x \Delta V}{\mathrm{R}^3} \right] \cdot \begin{bmatrix} J_x \\ J_y \end{bmatrix} = \left[B_z \right], \tag{2}$$

where J_x, J_y are the current density components on elements, ΔV represents volumes of elements and R are the distances between the centers of elements and arbitrarily points. The potential distribution on the boundary can be calculated using the following approximation on a boundary element

$$\mathbf{J}(x,y) \approx -\sigma \sum_{j=1}^{3} U_j \,\mathrm{grad} N_j(x,y)\,. \tag{3}$$

This new approach was tested on several different examples which have demonstrated various cases of skull fractures or brain diseases. The stability and the accuracy of a new reconstruction process were compared with the current method. Some results are presented further.

2. RESULTS OF BLOOD CLOT DETECTION

The numerical simulation results of the testing algorithm are obtained using a 2D FEM model which represents a simplified horizontal slice of the human head. This FEM model consisting of 2360 elements and 1237 nodes is shown in Figure 1a. Twenty electrodes have been used for the voltage measurement on the boundary of the investigated object.

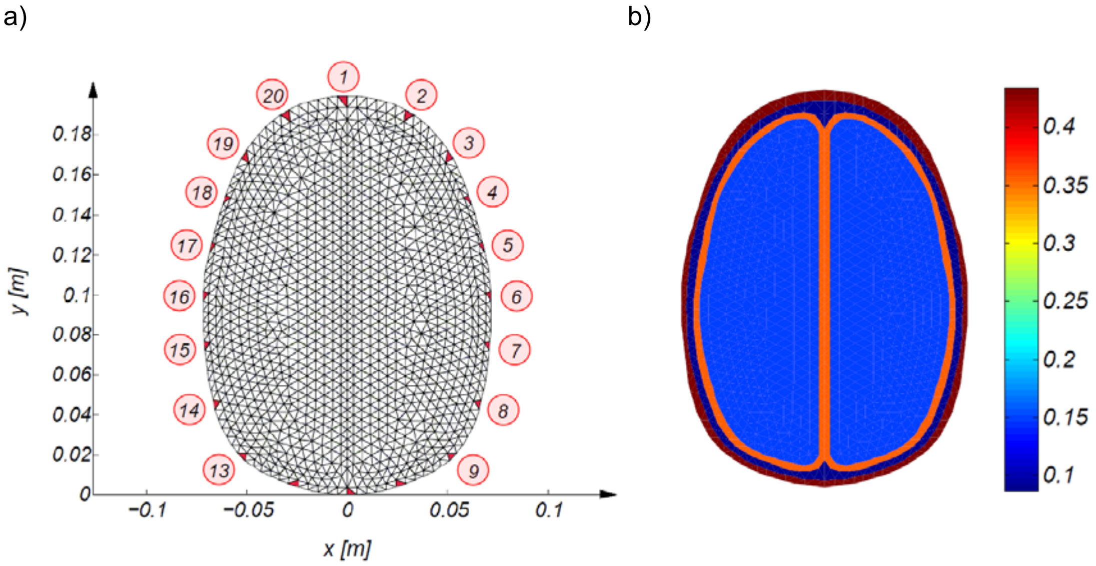

Fig. 1. A 2D FEM model for the modeling of brain tissue (a) and the arrangement of the healthy tissue (b)

A model of 2D arrangement with the original conductivity distribution (Fig. 1b) was used to simulate voltage $\mathbf{U}_M$. This is a simplified model of the head, which consists of just four homogeneous isotropic layers: scalp, skull, brain (gray and white matters). The conductivity values of different biological tissues used for the following simulation are presented in Table 1.

TABLE 1
Conductivity values of biological tissues

Tissue name	Colour	Conductivity [S/m]	References
Scalp	Brown	0.435	[6]
Skull	Dark blue	0.087	[6]
Gray matter	Orange	0.352	[7]
White matter	Blue	0.147	[7]

An original conductivity distribution with a tissue defect, namely a blood clot, is shown in Figure 2a. The conductivity of this nonhomogeneous subregion is 0.3 S/m [8]. It is supposed to be inside the white matter region, right hemisphere.

The first conductivity reconstruction algorithm represents the EIT algorithm based on a combination the Tikhonov regularization method (TRM) and the level set method (LSM). The results, which illustrate this reconstruction process, can be seen in Figures 2b, 2c: the conductivity distribution after the first use of the TRM (the first part of algorithm) in Figure 2b, the reconstruction result after using the LSM (the second part) in Figure 2c. The final conductivity distribution obtained after applying TRM the second time (the third part) is identical with the original distribution (Fig. 2a).

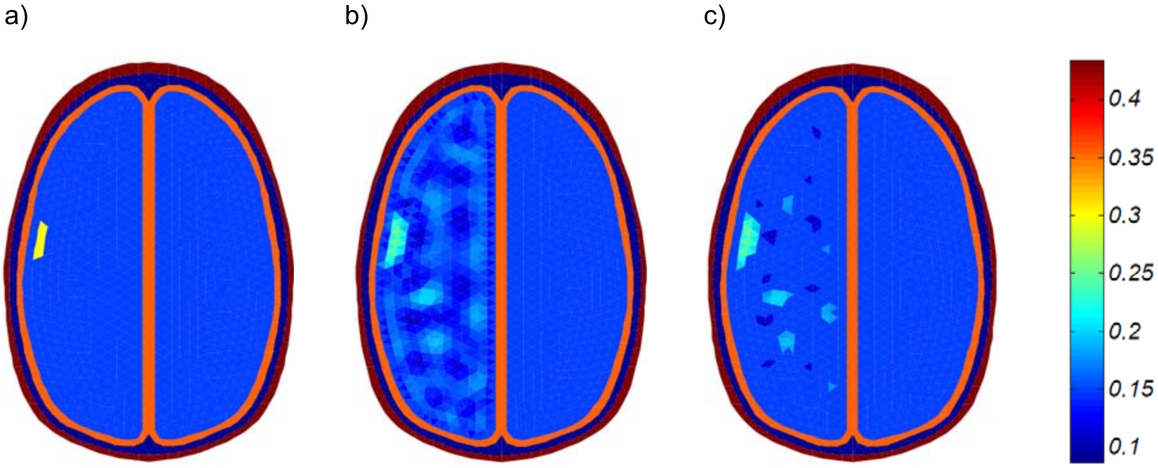

Fig. 2. An original conductivity distribution (a); the conductivity distribution after the first using the TRM the first time (b) and after using the LSM (c)

The same conductivity distribution as the original one (Fig. 2a) was obtained as a result of imaging by using the second algorithm, namely the algorithm based on the measurement of magnetic flux density.

All parameters of these successful reconstruction processes are presented in Table 2.

TABLE 2
Parameters of the reconstruction process

	1^{st} algorithm	**2^{nd} algorithm**
Starting value of α	5e-5	5e-8
Finite value of α	3.26e-16	1.24e-17
Change of α	0.2	0.7
Objective function $\Psi(\boldsymbol{\sigma})$	6.59e-24	3.71e-24
Number of iteration	28	62

The behaviour of the objective function for each foregoing algorithm is compared in Figure 3.

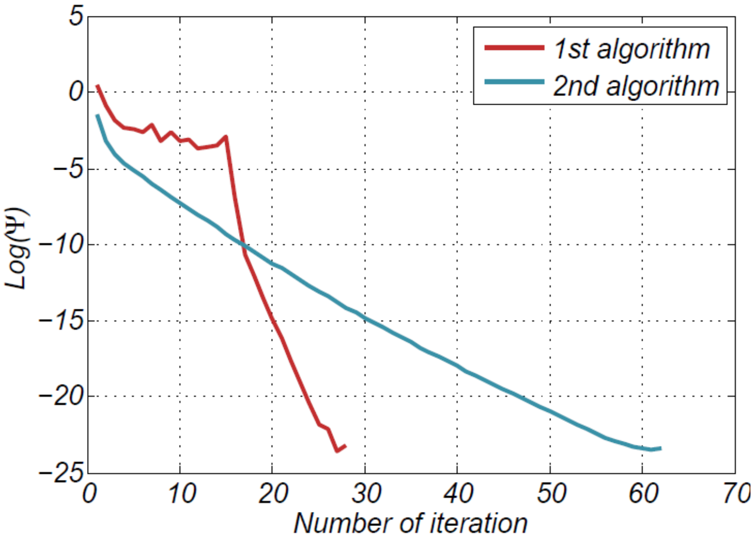

Fig. 3. The objective functions during detection of the blood clot

3. CONCLUSION

The proposed new way of an image reconstruction based on the measurement of magnetic flux density enables to obtain stable and accurate results as compared with the used EIT algorithm. However, the realized numerical tests show that this reconstruction process is more time consuming. This problem can be solved by introducing additional techniques.

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LITERATURE

1. Holder D. S.: Electrical Impedance Tomography, IOP Publishing, Philadelphia, 2005.
2. Sikora J., Wójtowicz S.: Industrial and Biological Tomography. Theoretical Basis and Applications. Electrotechnical Institute, Warsaw, 2010.
3. Seo J. K., Kwon O., Woo E. J.: Magnetic resonance electrical impedance measurement tomography (MREIT): conductivity and current density imaging. Journal of Physics: Conference Series, 2005, vol. 12, pp. 140-155.
4. Lee T.H., Nam H. S., Lee M., Kim Y. J., Woo E. J., Kwon O.: Reconstruction of conductivity using the dual-loop method with one injection current in MREIT. Phys. Med. Biol. 55 (2010) pp. 7523-7539.
5. Law S.K.: Thickness and resistivity variations over the upper surface of the human skull, Brain Topogr., 1993, no. 2, pp. 99-109.
6. Ramon C., Schimpf P.H., Haueisen J.: Influence of Head Models on EEG Simulations and Inverse Source Localizations. BioMedical Engineering Online, 2006, vol. 5, no. 10.
7. Barber D.C., Brown B.H. Applied Potential Tomography. Journal of Physics E: Scientific Instruments, 1984, vol. 17, no. 9, pp. 723-733.
8. Miklavčič D., Pavšeli N., Hart F.X. Electric properties of tissues, Wiley Encyclopedia of Biomedical Engineering, John Wiley & Sons, 2006.

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WDRAŻANIE DANYCH POLA MAGNETYCZNEGO DO TOMOGRAFII IMPEDANCYJNEJ

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STRESZCZENIE *W artykule przedstawiono nową modyfikację bieżącej technologii tomografii impedancyjnej. Ta nowa technologia jest stosowana do bezinwazyjnego obrazowania rozkładu przewodności tkanki głowy i jego zmian. Wprowadzono algorytm oparty na jednej składowej mierzonej indukcji pola magnetycznego. Zrekonstruowany obraz przewodności otrzymano przez iteracyjne rozwiązanie odpowiedniego równania macierzowego. Odpowiednio do przedstawionego algorytmu który stosuje jedną składową indukcji magnetycznej wykonano symulacje numeryczne dla dwuwymiarowego realistycznego modelu głowy ludzkiej (składającego się ze skalpu, czaszki i mózgu) z izotropowym docelowym rozkładem przewodności. Przy użyciu tego algorytmu można było otrzymać rekonstrukcję stosunków przewodności czaszki i mózgu nawet gdy tylko jeden prąd jest wprowadzony do mózgu.*