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MONITORING OF BRAIN TUMOR EVOLUTION USING IMPEDANCE TOMOGRAPHY

ABSTRACT *The paper proposes new technique for a non-invasive monitoring of local changes in a biological tissue based on impedance tomography. The injected current causes apart of the electric field inside the given object also the magnetic field. The new algorithm for conductivity image reconstruction, which uses the internal current information with respect to corresponding boundary conditions and one component of an external magnetic field, was developed. The internal conductivity distribution obtained using the proposed method is compared with those using conventional methods based on Electrical Impedance Tomography.*

Keywords: *electrical impedance tomography, biological tissue, magnetic field, conductivity, electric field, electrical capacitance tomography, magnetic flux density, voltages, magnetic resonance.*

1. INTRODUCTION

Electrical impedance tomography (EIT) or electrical capacitance tomography is an imaging tool that estimates the electrical properties at the interior of an object by measurements made at its surface [1, 2, 3]. Usually, EIT currents are injected into the object through electrodes placed at its surface, and the resulting

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voltages across other electrodes are measured. The current flow is determined by 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. This problem is more serious when the object to be imaged is e.g. a human head. An accurate human head conductivity imaging is important for the diagnosis and therapy of brain diseases [4]. Recently, magnetic resonance electrical impedance tomography (MREIT) has been proposed to provide noninvasive high-resolution imaging of electrical impedance within an object [5, 6]. MREIT is based on principles of magnetic resonance current density imaging technique and EIT. A current is injected into the object through a pair of surface electrodes, and the induced magnetic flux density **B** inside the object is measured by means of an MRI scanner. Early works on MREIT were based on minimization of the difference between the current density measured by MRI and the current density as a function of the conductivity. Unfortunately using the current density to reconstruct conductivity images requires obtaining all three space components of **B**. In the proposed paper we assume the measurement of B_z magnetic field component outside an object only.

2. BASIC THEORY

The current injected into the object through a pair of surface electrodes induces magnetic flux density **B** inside and outside the object. This magnetic field **B** can be measured, but also it can be calculated using the Biot-Savart´s law

$$\mathbf{B} = \frac{\mu_0}{4\pi} \int_V \frac{\mathbf{J} \times \mathbf{R}}{R^3} \, dV \qquad (1)$$

The components of current density **J** distribution inside the object can be obtained using (1) and the value of the B_z component can be measured. It can be described by a set of 2NE equations

$$\begin{bmatrix} \mathbf{K}_{Ry} & \mathbf{K}_{Rx} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{J}_x \\ \mathbf{J}_y \end{bmatrix} = \begin{bmatrix} \mathbf{B}_z \end{bmatrix} \qquad K_{Ry} = \frac{\mu_0}{4\pi} \cdot \frac{R_y \Delta V}{\mathrm{R}^3}, \quad K_{Rx} = \frac{\mu_0}{4\pi} \cdot \frac{-R_x \Delta V}{\mathrm{R}^3} \qquad (2)$$

The current density **J** can be obtained also from potential distribution using appropriate linear approximation on element (e)

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

The image reconstruction algorithm is based on minimizing of suitable objective function $\Psi(\sigma)$ relative to σ. To solve this inverse problem the deterministic approach based on the Least Squares method and the standard Tikhonov Regularization method was used

$$\min_\sigma \Psi(\sigma) = \min_\sigma \left[\frac{1}{2} \sum \left\| \mathbf{J}_M - \mathbf{J}_{FEM}(\sigma) \right\|^2 + \alpha \frac{1}{2} \left\| \mathbf{L}\sigma \right\|^2 \right] \tag{4}$$

where σ is the volume conductivity distribution vector in the object, $\mathbf{J}_\mathrm{M}$ is the current density vector recalculated from the measurement of the magnetic flux density $\mathbf{B}$, and $\mathbf{J}_\mathrm{FEM}(\sigma)$ is the vector of calculated current density relatively to σ, which can be obtained using FEM, α is a regularization parameter and $\mathbf{L}$ is a regularization matrix.

3. RESULTS OF MONITORING BRAIN TUMOURS

A series of computer simulations was conducted to assess the performance of the proposed algorithm in two-dimensional piecewise homogeneous model of human head. This simplified model consists of four homogeneous isotropic layers: scalp, skull, brain (gray and white matters). The conductivity of the homogeneous region representing scalp is 0.435 S/m, the conductivity of the skull region corresponds to 0.087 S/m, the conductivity of the region representing grey matter is 0.352 S/m, and the conductivity of the two regions representing white matter is 0.147 S/m [7].

One of the carried out simulations is shown in Figure 1. The aim of this simulation consists in evaluation of the electrical conductivity changes of the brain tissues, particularly in monitoring brain tumors with the conductivity value of 0.9 S/m. The reconstruction result of conductivity distribution by applying the conventional EIT algorithm based on the Tikhonov regularization method can be seen in Figure 1a. The theoretical background of this algorithm is presented in [8]. The result of imaging for the proposed algorithm is shown in Figure 1b.

These two algorithms were used on the condition that the geometry and values of healthy tissue conductivity were known. Furthermore, the value of tumor conductivity was known too.

a) b)

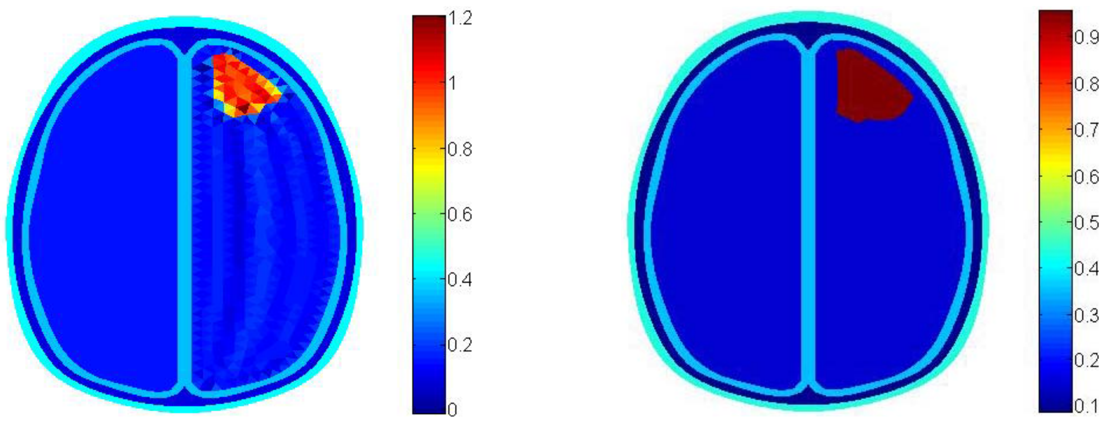

Fig. 1. Tumor detection results:
the conventional algorithm (a), the proposed algorithm (b)

In the cases of further tumor monitoring by using the proposed algorithm, namely to estimate of efficiency treatment of this disease, the region of probable localization of a tumor will be tested in the vicinity of the previous localization of the tumor (Fig. 2b) within one layer of finite elements surrounding this tumor region. Thereby, the number of elements with unknown conductivity was reduced. This result was used for a significant simplification of the reconstruction process and for saving the time necessary to materialize the solution.

The reconstruction result of the conductivity distribution in the case of tumor growth is shown in Figure 2a. The results of monitoring two tumor shrinkage stages can be seen in Figure 2b, 2c.

a) b) c)

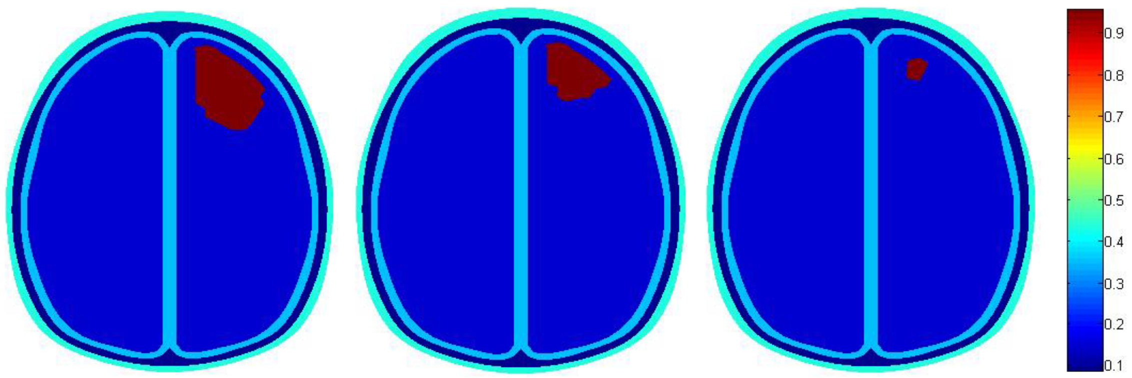

Fig. 2. Monitoring three tumor stages by applying the proposed method:
the growth of tumor (a), the tumor shrinkage (b) and (c)

An additional condition was introduced into the iteration process to increase the imaging speed of the proposed algorithm. This filter was realized as follows:

$$IF\ \sigma(i) \leq 1.1 \cdot \sigma_{WM},\ THEN\ \sigma(i) = \sigma_{WM},$$

where σ_{WM} is the conductivity of white matter.

The behaviour of the objective function for each simulation obtained using the foregoing approach is compared in Figure 3. All reconstructions were successful. In order to obtain a useful reconstruction, it was necessary to set parameter $\alpha = 5 \cdot 10^{-9}$ and parameter $d\alpha = 0.7$. The imaging results were obtained with relative error less than 1%. Parameter $d\alpha$ [10] is used to adaptively change of a parameter α during an iteration process $\alpha = \alpha * d\alpha$ if this process is stable otherwise $\alpha = \alpha / d\alpha$.

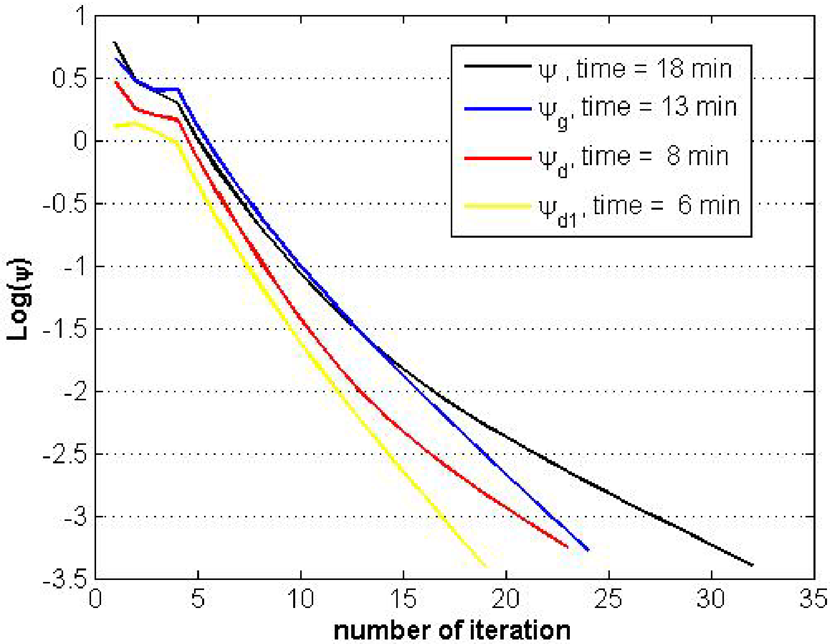

Fig. 3. The objective functions during reconstruction

4. CONCLUSIONS

Presented examples demonstrate the feasibility of the new approach of an image reconstruction based on measurements of one magnetic field component (B_z) outside a given object. Based on obtain results it is possible to say, that this new way offers a useful tool for an efficient, stable and reliable image reconstruction of biologic tissue changes with high accuracy.

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OBSERWACJA ROZWOJU GUZA MÓZGU PRZY UŻYCIU TOMOGRAFII IMPEDANCYJNEJ

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STRESZCZENIE *Artykuł proponuje nową metodę nieinwazyjnej obserwacji lokalnych zmian tkanki biologicznej opartej na tomografii impedancyjnej. Wprowadzony prąd powoduje oprócz pola elektrycznego wewnątrz danego obiektu także powstanie pola magnetycznego. Został opracowany nowy algorytm do rekonstrukcji obrazu przewodności wykorzystujący informację od wewnętrznego prądu, odpowiednio do warunków brzegowych i jedną składową zewnętrzną pola magnetycznego. Rozkład wewnętrznej przewodności otrzymany przy użyciu proponowanej metody porównano z wynikami konwencjonalnych metod opartych na Elektrycznej Tomografii Impedancyjnej.*