ELECTROIMPEDANCE TOMOGRAPHY AS A TOOL FOR BRAIN EXAMINATION

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Abstract: The aim of this paper is to discuss the possibility of a successful Electroimpedance Tomography (EIT) reconstruction of an impedance distribution within a human head taking into consideration the presence of a skull and its screening effect for electrical signals. The results of numerous computer simulations of the processes of impedance measurements and 3D EIT reconstruction are presented. The volume of the smallest recognisable perturbation within both brain and skull areas are determined as well as their relationships with the required contrast. The unquestionable usefulness of EIT approach for the purposes of impedance modelling is proven.

Keywords: electroimpedance tomography, EIT, impedance modelling, EEG propagation analysis, head model

1. Introduction

The impedance properties of a human head are of great importance for medical examination of both the structure and the activity of a brain. The knowledge of a spatial impedance distribution inside a head can be useful both in clinic and research for distinguishing abnormal areas of brain characterised by their different amount of blood. The analysis of the processes of generation and propagation of electrical signals seems to be another promising application of such an information. The impedance models of head have so far been constructed on the basis of MR images. In such an approach the assumption of tissue homogeneity is made, which was proven to cause significant location errors.

The electroimpedance tomography is a method of representation of an impedance distribution inside certain object on the basis of measurements made on its surface. The results of simulations and phantom studies performed in the

Department of Medical and Ecological Electronics (DMEE), Technical University of Gdansk show, that the successful reconstruction of impedance perturbation of relative volume as small as 1% is fully feasible [1–3]. Those studies were however carried out with reference to breast examination and thus the assumption of homogenous background had been made. The impedance approach seems to be also a very promising method providing us with the detailed information on impedance structure of a head, helpful in the case of EEG propagation analyses. The possibility of joining impedance measurements with standard EEG examination using the same set of electrodes presents an additional advantage, which is extremely important from medical point of view. What's more, the common geometry of both examinations significantly simplifies the process of merging multimodality data sets. The studies presented in this paper deal with the problem of feasibility of a successful reconstruction in a more complex environment — a three–layer, hemispherical head model (scalp–skull–brain). The relative volume and contrast of minimal recognisable perturbation inside brain tissue are sought. The work preliminary is performed as computer simulation.

2. Method

2.1. Model

The model is based on a hemispherical mesh of finite elements composed of tetrahedral cells representing complex electrical properties of head tissues. In such environment a three–layer (scalp–skull–brain) model of a head was designed. Individual layers represent the average values characteristic of such kind of tissue as presented in Figure 1.

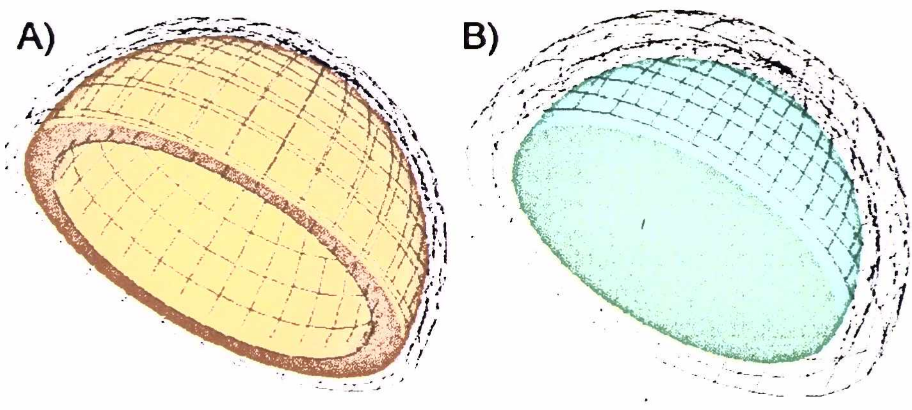

Figure 1. *The three–layer model of a head (the layers representing skull A and brain B have been marked)*

The model allows simulating the presence of a spherical perturbation of electrical properties of tissue. The relative volume, contrast and location of the perturbation can be freely adjusted as shown in the Figure 2. The set of 64 complex measurement electrodes and one reference electrode is located on the surface of the model.

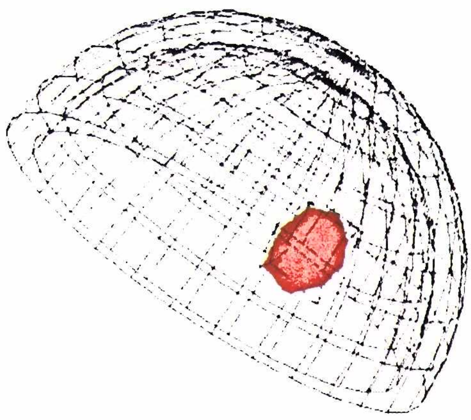

***Figure 2.** The perturbation of impedance properties of brain (relative volume 10%, contrast 450%)*

The geometrical data concerning the measurements of individual layers may be collected on the basis of computer–aided tomography and the locations of electrodes can be obtained by means of three–dimensional digitizer.

2.2. Reconstruction algorithm

The studies are performed by means of the Technical University of Gdansk Electroimpedance Tomograph simulation and reconstruction software. The applied reconstruction algorithm called Regulated Correction Frequency ART (RCFART) is a generalised absolute algebraic reconstruction perturbation method [4, 5] presented by equation (1):

$$\sigma_e^{(h+1,i)} = \sigma_e^{(hi)} + k\sigma_e^{(hi)} \frac{\sum_{j=1}^{L/H} \sum_{k=1}^{K} c_k^{(li)} s_{p(k,l)e}^{(i)}}{\sum_{j=1}^{L/H} \sum_{k=1}^{K} \left| s_{p(k,l)e}^{(i)} \right|}, \qquad (1)$$

$$\sigma_e^{(1,i+1)} = \sigma_e^{(H+1,i)}.$$

For prescribed iteration i, in succeeding corrections $h = 1, \ldots, H$, values of σ_e (con-ductivity of model elements) are modified for a subset of L/H uniformly spre-ad excitations l. Corrections are proportional to the current value of conductivity $\sigma_e^{(hi)}$, normalised covariance of relative changes $c_e^{(li)}$ of k–th measured currents, calculated for l–th excitation and sensitivity $s_{p(k,l)e}^{(i)}$ of these measurements to chan-ges of element e performances. At the beginning of each iteration values of cur-rent sensitivities to conductivity changes are calculated. The correction frequency H should be equal to L/n where n is a natural number.

2.3. Reconstruction quality criteria

To compare the quality and efficiency of reconstruction the following criteria are applied:

— the current error E_l defined as relative mean square deviation of measured currents i_p from calculated $i_p^{(l)}$ at the beginning of the last iteration. In the presented simulations the error is regarded as the criterion of algorithm convergence:

$$E_l = 100\sqrt{\sum_{p=1}^{P}(i_p - i_p^{(l)})^2 \Big/ \sum_{p=1}^{P} i_p^2}\,, \tag{2}$$

— the background error E_B defined as a relative mean square deviation of admitivity of the reconstructed picture from the test picture in the background area:

$$E_B = 100\sqrt{\frac{\sum_{\Lambda_e \subset B}(\alpha_e^{(l+1)} - \alpha_B)^2 V_e}{\alpha_B^2 V_B}}\,. \tag{3}$$

The perturbation is considered as feasible to be distinguished if the current error is convergent and the background error doesn't exceed 30% at the same time.

3. Methodology

The presented research is expected to answer the following questions. First, whether the EIT technique is able to deal with reconstruction of complex objects such as human head, which is characterised by enormous range as well as sudden changes of its electrical properties. If so, how the accuracy of assumed starting model influences the quality of reconstructed picture. And finally, whether it is possible to apply the method for the purposes of improving the quality of impedance model. In the case of head examination it mainly means the precise reflection of inhomogeneous skull structure.

To answer those questions numerous series of simulation and reconstruction processes have been carried out. In order to determine the impact of the accuracy of a starting model on the quality of reconstructed picture, three series of experiments were planned. In the first (marked as A series) the starting model for iterative reconstruction algorithm was identical as the presumed model. In the other some discrepancies coming from individual differences of skull structure and its internal inhomogeneity were taken into consideration. In the B series the thickness of skull layer was modified to 120% and its admittance to 90% of their original values. In the C series the skull layer was divided into two sublayers of admittances 80% and 120% of the previously modelled value. The results in the form of the relationship between the minimal recognisable relative volume and the required contrast are presented in the Figure 4. The hypothetical perturbation and its reconstructed picture are depicted in the Figures 2 and 3.

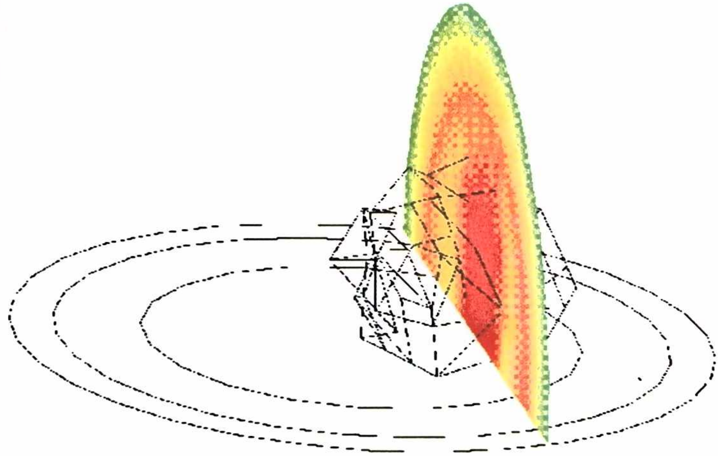

Figure 3. *The reconstruction of perturbation from Figure 2 (the crossection through the center of modelled perturbation as well as the contour of the area corresponding with properties within range 80–120% of modelled impedance have been presented)*

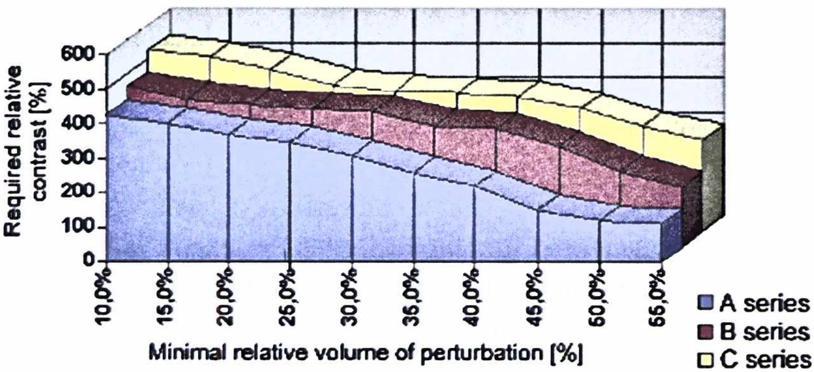

Figure 4. *The mutual relationship between the relative volume and contrast of the minimal recognisable perturbation of brain tissue. (The perturbations corresponding with the area above the chart can be recognised according to presumed criteria.)*

As poor geometric resolution of EIT technique, especially in the centre of a model, is commonplace, it is rather hard to expect the results to be precise enough to be applied for distinguishing pathological areas in medical diagnosis. However the boundary resolution of this approach, seems satisfactory for the purposes of improving the quality of impedance model of a human head, especially for distinguishing the inhomogeneities of the skull. Thus the next step of the research is devoted to feasibility of locating inhomogeneous areas within a skull structure.

The model including a 250% contrast perturbation in the skull layer was also designed (Figure 5) and the smallest recognisable volume was sought according to the same criteria.

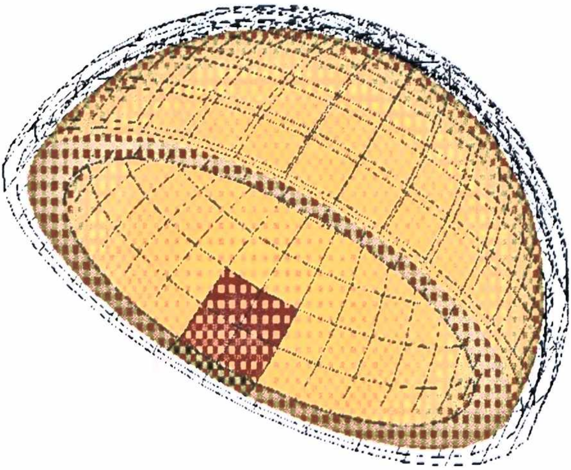

Figure 5. A hypthetical perturbation within the skull layer

In this case a region as small as 3% turned out to be fully recognisable regardless of its location.

4. Results and Conclusions

Although still at a preliminary stage, the presented results allow to formulate the following conclusions:

- the EIT technique can be successfully applied to objects characterised by complex impedance structure and considerable range of impedance values;
- according to presumed conditions the smallest recognisable volume within a brain area amounts to 10% for the contrast as high as 425%;
- for the practically achievable contrast of 250% the minimal recognisable volume increases to more than 35%;
- the quality of reconstruction strongly depends on the accuracy of impedance model used as the starting point of the iterative reconstruction algorithm;
- the fidelity of an electrical image of a skull in respect of both its shape and internal impedance structure is crucial for proper reconstruction of objects located inside;
- the EIT approach can be successfully applied as a method for improving electrical properties of impedance model constructed on the basis of anatomical information.

The proven above, strong relationship between the quality of reconstruction and the accuracy of a starting model definitely confirms the purposefulness of the further research in the field of precise modelling and in particular, of imaging the impedance structure of a skull. Our current research aims to replace a simple layer–model with the detailed model constructed on the basis of joined tomographic and impedance data for further studies of the reverse problem in EEG.

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