source localization,
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LOCALIZATION OF ELECTRICAL ACTIVITY IN THE BRAIN

The electrical activity in the brain is observed as distribution of electric potentials on a scalp and as magnetic field over the head. Localization of the active sources within the brain based on EEG or MEG recordings is frequently used by neurologists. A computer program DIPOLE elaborated in Institute of Precision and Biomedical Engineering for mapping and localization of active sources in the brain is presented. Different models of head can be applied. Methods for construction models of the head from images of the brain slices are described. A model compost of volume elements which can take into account an anisotropy and the inhomogeneities of the tissues is also presented. This can significantly increase an accuracy of the localization of the active sources within the brain. The program enables creation the models with parameters which can be set by a user for every individual case and which are conformable to a growing knowledge about the electrical properties of the head tissues.

1. INTRODUCTION

The brain with its surrounding tissues is a multicompartment electrical conductor. The activity of the source is observed as the distribution of electric potentials on a scalp and as magnetic field over the head. The EEG (electroencephalographic) and/or MEG (magnetoencephalographic) signals are then used to perform a localization of the active sources within the brain, what is known as inverse problem. In order to obtain the high localization accuracy one should use a model of the head applying a realistically shaped geometry and the detailed electrical properties of the tissues. One of the most popular method to locate an active source within the brain involves Levenberg-Marquardt algorithm. The know advantages of this algorithm are efficiency and accuracy, the biggest disadvantage is that a physician must set the initial source parameters (position and orientation of a dipole) before starting a localization procedure. For instance if the initial source position is set far away from a region of interest the procedure can be trapped in local minimum. Since a standard process of localization often requires many trials for different initial parameters, we propose a simple and fast scanning algorithm which is able to find such parameters automatically. The algorithm independent on head model (sphere-like, realistic) and type of measurement (EEG, MEG) enables the physician avoid checking many initial source configurations.

The objective of this research is to develop program for study the temporal and spatial patterns of the EEG and localization of active areas. The locations of the sources inside the brain are performed

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using models of the head and of the generator. Source locations is of high importance for the functional organization of the brain and enable the development of clinical tools for diagnosis. This tool is complementary to some of the other modalities used for brain examination such as the X-ray tomography and magnetic resonance imaging.

2. ACTIVE SOURCES

The most frequent model of a source applied in clinics is current dipole described as

$$p = \lim_{\Delta l \to 0} I \Delta l \qquad (1)$$

where: I –current in the segment Δl→0.

In more complicated phenomena the active area can be modeled by a few current dipoles.

3 MODELS OF HEAD

3.1 SPHERICAL MODELS

The volume conductor is often described by a compartment model, in which each compartment is considered to be homogeneous. In literature one can find volume conductor models of varying degrees of sophistication. Models describing the head range from concentric spheres, eccentric spheres, realistically shaped models describing the brain, the skull, and the scalp. Models describing the torso range from a homogeneous isotropic semi-infinite space, realistically shaped models including inhomogeneities, such as the lungs, the heart, the spinal region and ventricular cavities.

The simplest and most frequently used model of the head is one compartment sphere. For spherical model exist analytical solution of forward problem of electric potential and magnetic field distribution [1, 3, 4],

$$V_o = p \cdot f(r_s, r_o) \qquad (2)$$

$$B_o = p \times f(r_s, r_o) \qquad (3)$$

where: V_o – electric potential in point of observation
B_o – magnetic induction in point of observation
p – current dipole
f – function dependent of applied model
r_s and r_o – source and measurement points

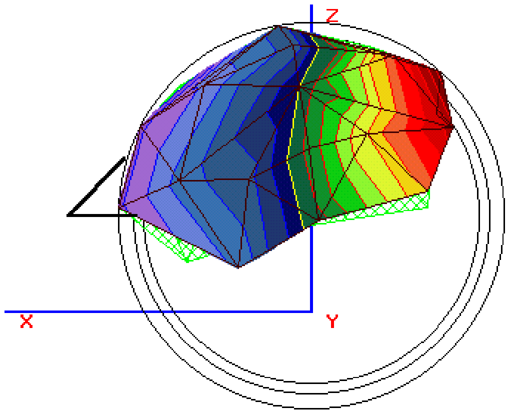

Fig. 1 Three compartment spherical model with potential distribution.

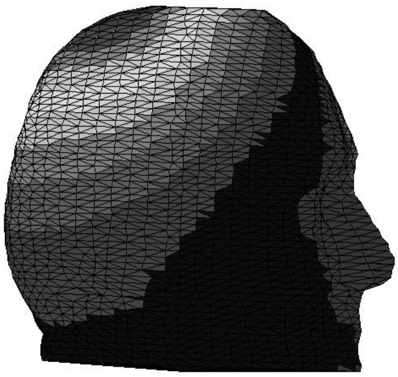

Fig. 2. Realistically shaped volume conductor model

Solving the forward problem for realistically shaped volume conductor models requires a numerical method. In the most exact the method should be capable of handling models that incorporate inhomogeneities and anisotropy. Our experiences indicate that incorporating such detailed description of the tissues is of high importance, especially in cases when an active source within the brain is located close to a region with the inhomogeneities like holes in the skull, scars etc.

4. DIPOLE PROGRAM FOR LOCALIZATION

In many studies, the objective is to localise the sources that generate a measured distribution of potentials (EEG) or magnetic field (MEG). This inverse problem has no unique solution, as there are many source configurations that produce exactly the same measured potential or magnetic field. The solution is often constrained using a-priori information about the sources, for example, by assuming a certain number of current dipoles sources and their location. The inverse problem is solved in an iterative process. A forward computation needs to be performed for each estimate of the source configuration. The computed potentials or magnetic fields are compared with the measured. The difference is expressed as a value, often a summated square difference, which is a function of the source parameters. The source configuration taken, is the one minimising this so-called goal-function. Several procedures exist for finding this minimum. The procedure which is used for solving the inverse problem is the Marquardt algorithm.

The models based on a finite element meshing are semi-automatically constructed from MRI (Magnetic Resonance Imaging) or CT (Computer Tomography) images of the brain slices using a computer program developed in our group. The volumes of the head compartments (scalp, skull, cerebro-spinal fluid, brain) are found using a border detection and region growing algorithm. The volumes are then divided into the tetrahedral elements of a certain size by means of 3D Delaunay triangulation procedure. Since the whole volume of head is divided into the discrete elements, it is possible to describe every tetrahedral element by a conductivity tensor. A user can manually choose the elements which should have non-standard values of the conductivity. An accuracy of the model can be also increased by a local refinement of the tetrahedral mesh and by inserting additional elements with known conductivities.

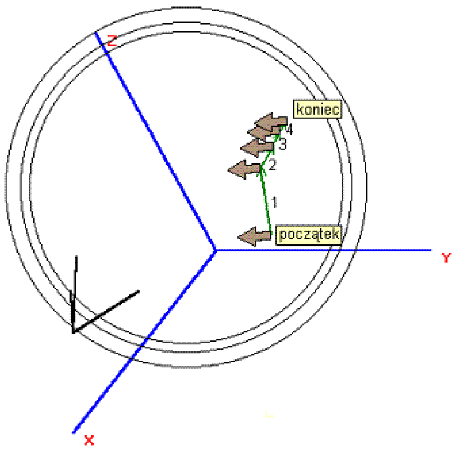

Fig. 3. Iteration method.

The program written in our group is equipped with a database. The growing knowledge of the electrical properties of the tissues can be saved and used during a process of construction of the individual models. The known drawbacks of the commonly used models of head (like spherical and boundary element models) are they not include the inhomogeneities and/or an anisotropy of the tissues. The finite multi element models are much more complicated but can provide very detailed description of the electrical properties of the tissues.

The accuracy of the predicted source locations must be established with respect to the gold standards in each research area, for example, to depth recording in epilepsy, to MR images in stroke and to the psychometric testing in cognitive studies.

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