INVESTIGATING THE EFFECTS OF EYE CONDUCTIVITY ON EMSI FORWARD PROBLEM USING A REALISTIC BEM HEAD MODEL

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Abstract: **In this work, a method is developed to obtain realistic head models for the Forward Problem of Electro-magnetic Source Imaging (EMSI). The Boundary Element Method (BEM) is used for the solution of the forward problem and the effects of conductivity distributions on the solutions are investigated. The scalp, skull, gray matter (GM), white matter (WM) and eyes are segmented using multimodal MR images and the meshes for the corresponding surfaces are created. To include the eye tissues into the model** *intersecting meshes* **are generated. Note that the method of intersecting meshes has not been used before in the problem of electro-magnetic source imaging. The effect of the eye tissues on the forward problem solutions is investigated. Models for the whole head with and without eyes are compared by calculating Relative Difference Measures (RDM) of electric potentials. It is observed that as the dipole gets closer to the eyes the RDM increases. With a tangential dipole located at 1.4 cm away from the eyes, and for eye conductivity of 0.5 S/m, RDM is calculated as 17%.**

INTRODUCTION

The ultimate goal of this study is to use realistic head models in Electro-Magnetic Source Imaging (EMSI). This paper is focused on the forward problem solution of EMSIs using realistic head models. This requires 1) a method to obtain an accurate head model from multimodal MR images, 2) and a numerical model that use this realistic head for the forward problem solution.

Using a simple spherical volume conductor model, it is possible to show that inhomogeneities close to sources can significantly affect the measured MEG and EEG [1]. When there are simultaneously active multiple sources, the accuracy of the head shape and head conductivity distribution becomes even more important. For these reasons realistic head models are preferred for the solution of the forward problem with realistic models numerical techniques must be employed. Realistic modeling studies have started in late 1980's [2], [3]. In recent studies with the Boundary Element Method (BEM), realistic head models that represent scalp, skull and cortex tissues are used [2],[3],[4]. In this study, first the method of realistic head modeling is explained for modeling head, a semi-automatic segmentation algorithm is developed that separates seven tissues (the scalp, skull, CSF, eye tissues, eyeballs, GM and the WM) of the head. Using the results of this segmentation, quadratic-triangular element meshes are formed for the interfaces of the tissues. The method of intersecting surfaces is used to represent the mesh of the skull and eyes. Quadratic, triangular meshes are created for the interfaces of the tissues. To include the eyes into our model an automatic mesh generation algorithm is used for the intersecting surfaces of the skull and eyes. The BEM formulation [5] employs triangular, quadratic, isoparametric elements to solve the forward problem. The effects of the eye tissues on the forward problem are then investigated.

DEVELOPMENT OF REALISTIC HEAD MODELS

In this work, segmentation is performed using the three-dimensional (3D) multimodal MR images of the head (T1, T2 and proton density (PD) images). A hybrid algorithm that uses snakes, region growing, morphological operations, and thresholding is applied to the images [6]. In mesh generation, first a very fine mesh is obtained by skeleton climbing. Next, the mesh is filtered and a coarsening process is performed according to Delaunay criteria. Topological corrections are also made. Using the resulting linear mesh, nodes are added to the midpoint of each edge. These points are placed to fit the original fine mesh and used to create quadratic elements that match the volume data. The details of the segmentation and mesh generation algorithms can be found in [7] and [8].

To include the eyes into our model, an automatic mesh generation algorithm is used for intersecting surfaces. The eyes are situated in the cavities of the skull. The algorithm is applied to the outer surface of the skull and the eyes to obtain a unique mesh. Because of the robustness problems encountered in [7] and [8], the intersecting meshes are obtained using a different algorithm described in [9].

The mesh generation algorithm for intersecting the skull and a single eye can be summarized as follows:

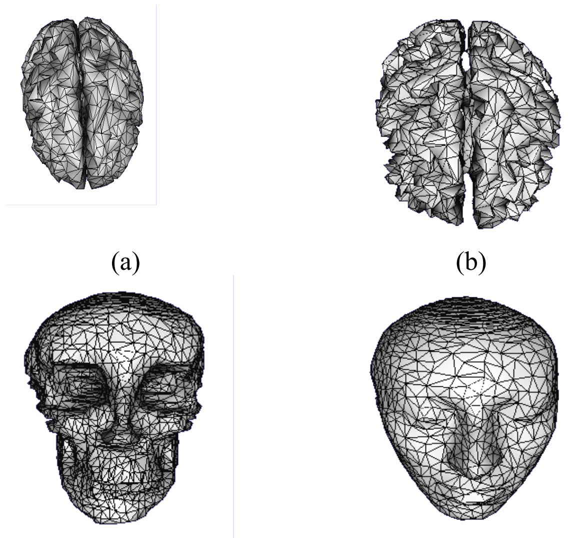
1. Find the intersections between skull and eye surfaces.
2. Determine a closed loop of intersection-line-segments.
3. Re-triangulate each intersecting triangle with new elements using the advancing front technique.
5. Identify resulting surface segments.
6. Remove the unnecessary elements.
7. Improve surface mesh quality.

The algorithm is repeated for the second eye.

RESULTS

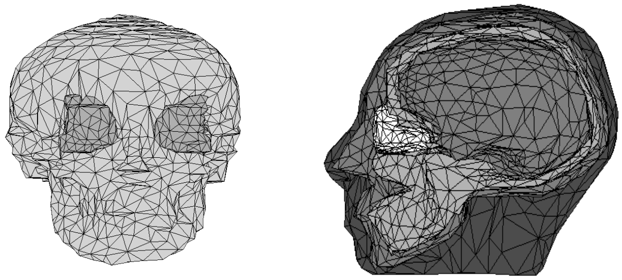
In this work segmentation is applied to the axial MR images with 72 slices, 3 mm thickness. The resulting meshes of cortex, white matter, skull and scalp are presented in Fig.1. The intersecting surfaces of outer skull and eyes are presented in Fig 2a, the final mesh is presented in Fig 2b. The mesh consists of 9680 nodes, 4864 elements and contains the following tissue types: Scalp (0.2 S/m), Skull (0.05 S/m), CSF (0.5 S/m), Brain (0.2 S/m).

The effect of the eyes on the forward problem solutions is then investigated. The Relative Difference Measures (RDMs) are calculated between two models: realistic model with eyes and a model without eyes (Fig. 3). It is observed that, as the dipole approaches to the eyes the effect of eyes become more significant.



(a) (b) (c) (d)

Fig 1. Meshes of (a) cortex, (b) WM, (c) skull, (d) scalp



(a) (b)

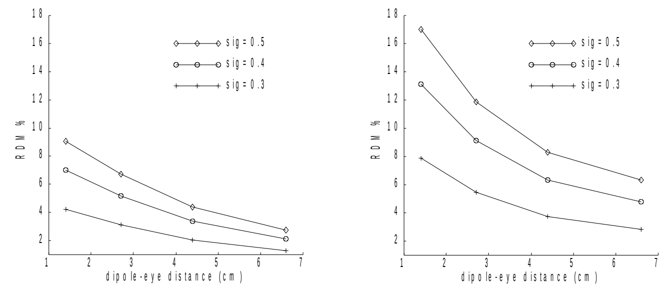
Fig 2. (a) Whole head mesh (b) intersecting mesh of the outer skull and the eyes.

For a mesh with 9680 nodes, the forward problem solution is obtained in 36 minutes on a 933 MHz Pentium III computer with 1GB RAM.

CONCLUSIONS

In this work, a semi-automatic segmentation algorithm was developed and a realistic head model with the scalp, skull, cortex and eye tissues was obtained. A hybrid mesh generation algorithm was used to generate meshes for the segmented volumes.

The effect of the eye tissues on the forward problem solutions is investigated. Whole head models with and without eyes are compared by calculating Relative Difference Measures (RDM). It is observed that as the dipole gets closer to the eyes the RDM increases. For a dipole parallel to the eyes located at 1.4 cm away from the eyes, and for eye conductivity of 0.5 S/m, RDM for electric potential is calculated as 9%. For a tangential dipole the RDM becomes 17%. This result is especially important to experiments related to the pre-frontal cortex.



(a) (b)

Fig 3. The RDMs obtained between the two head models: realistic head with eyes and the same model without eyes.

Since the model contains different tissue types, sensitivity of the forward and inverse problems to conductivity can be further investigated. In future studies, it will be possible to obtain more accurate inverse problem solutions that employ the realistic models.

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