DEVELOPMENT OF REALISTIC HEAD MODELS FOR ELECTRO-MAGNETIC SOURCE IMAGING OF THE HUMAN BRAIN

Z. Akalın, C. E. Acar, N.G. Gençer
Department of Electrical and Electronics Engineering,
Middle East Technical University, 06531, Ankara, Turkey

Abstract-**In this work, a methodology is developed to solve the forward problem of electromagnetic source imaging using realistic head models. For this purpose, first segmentation of the 3 dimensional MR head images is performed. Then triangular, quadratic meshes are formed for the interfaces of the tissues. Thus, realistic meshes, representing scalp, skull, CSF, brain and eye tissues, are formed. At least 2000 nodes for the scalp and 5000 for the cortex are needed to obtain reasonable geometrical approximation. Solution of the forward problem using our previous Boundary Element Method (BEM) formulation with quadratic elements remains to be made.**

***Keywords* - BEM, realistic head model, segmentation, mesh generation.**

I. INTRODUCTION

Electrical activities of the human brain due to body functions can be measured with electrodes placed on the scalp (EEG) and with magnetic sensors (MEG) placed near the scalp surface. The representation of electrical activity of the brain using electrical and magnetic measurements is called electro-magnetic source imaging (EMSI). The source of an electrical activity is usually modeled by electrical dipoles and the purpose of EMSI is to obtain information about the spatio-temporal behavior of these dipoles. An essential part of obtaining EMSIs is the solution of the electric and magnetic fields (the forward problem) for a given dipole configuration assuming a head model. The solution of the inverse problem (i.e., given the measured data, finding the location and direction of dipoles) is based on the comparison of the measured and calculated fields. To increase accuracy in EMSIs, the human head must be modeled accurately. The purpose of this study is twofold: 1) to obtain an accurate head model, 2) to solve the forward problem of EMSI for this model.

In the earliest studies, head models with simple geometries having analytical solutions for a dipole inside the conductor model were used. The simplest head model is the homogeneous sphere. Other homogenous head models that may represent the head shape are prolate spheroid (egg-shape). In order to represent layers like skull, scalp and cerebrospinal fluid (CSF), concentric and eccentric spheres models were used. Such models also have analytical solutions for a dipole inside conductor model [1].

The localization results have shown that the use of simple head models can lead to significant errors in the source parameters. Using a simple spherical volume conductor model, it is shown that inhomogeneities close to sources can significantly affect the measured MEG and EEG [2]. When there are simultaneously active multiple sources, the accuracy of the head shape becomes even more important. For these reasons realistic head models are used [3]. There are no analytical solutions for realistic models, therefore numerical techniques must be used. The most important ones of these methods are Finite Element Method (FEM) and Boundary Element Method (BEM). In FEM the volume data is represented with volume elements. Therefore a large number of elements are used for good representations of the head. In BEM, the tissue interfaces are represented with surface elements. Therefore fewer elements are used compared to FEM.

The head geometry is obtained from MR images. For image segmentation, a hybrid algorithm that uses 'snakes', region growing, morphologic operations, and thresholding is applied [4]. Scalp, skull, CSF, eyes and eyeballs, white matter and gray matter are segmented. Boundary Element mesh with quadratic elements is created from the segmented data. Tissue boundaries are triangulated by adaptive skeleton climbing (ASC) algorithm [5]. A smoothing algorithm is used to remove the noise and artifacts caused by slices of MR images [6]. Thereafter a coarsening algorithm is used to represent the tissues with less number of triangles [7]. Finally, the resulting mesh is corrected topologically [8]. Up to this step linear elements are used. After obtaining the coarse mesh, the elements are converted to quadratic elements using the original segmentation data.

In this study, the segmentation and mesh generation algorithms are explained. Meshes created for cortex, white matter, scalp and skull meshes are presented. The BEM formulation [9] which employs triangular, quadratic, isoparametric elements will be used to solve the forward problem of EMSI.

II. SEGMENTATION

Segmentation is a process of classifying elements having the same properties in one group. In this work, segmentation of scalp, skull, CSF, eyes, gray matter and white matter are performed from the 3 dimensional multimodel MR images of the head (T1 and proton density (PD) images are used). A hybrid algorithm that uses 'snakes', region growing, morphologic operations, and thresholding is applied. The algorithm used for segmentation is given in Fig. 1.

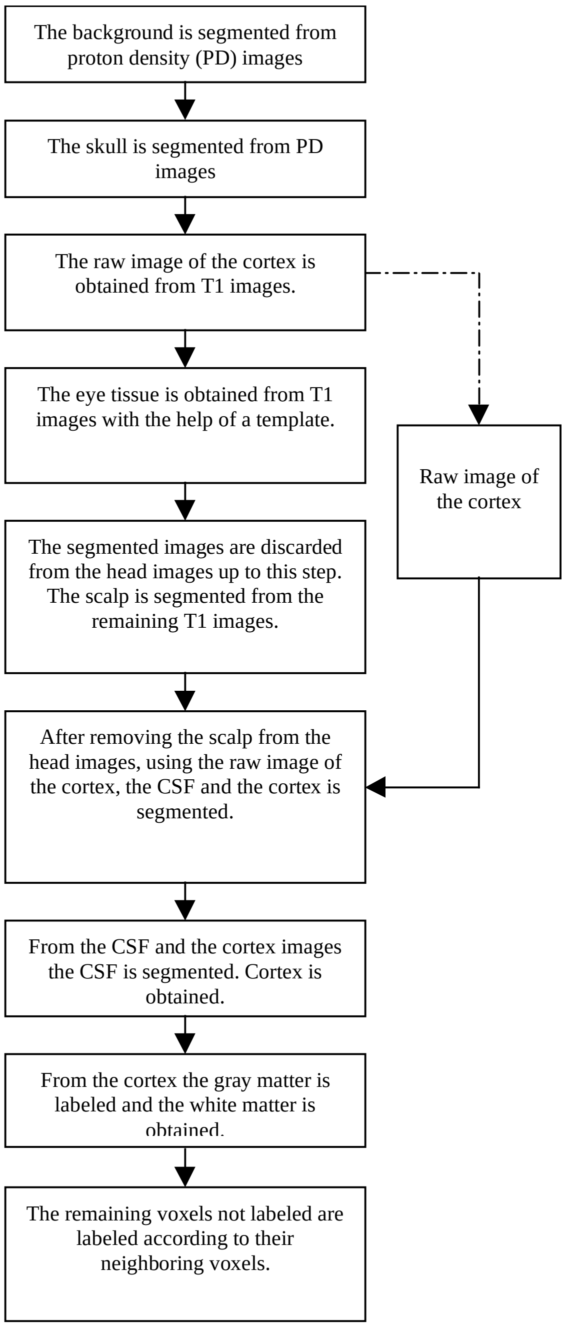

Figure 1 : Algorithm used in segmentation

The segmentation begins by removing the background from volume data. For this purpose 'snake' algorithm is used over PD images. After removing the background, skull and sinus regions are extracted from the PD image using thresholding. A raw image of the brain is obtained from T1 images using thresholding and region growing. To locate the eyes an eye template is obtained from a T1 slice where the eyes are most significant. Using this template and a user defined threshold eyes are segmented at each slice and extracted using morphological operations. The remaining structures are isolated and segmented by morphological operations and 3D region growing. In Figure 2 the segmented head images are presented:

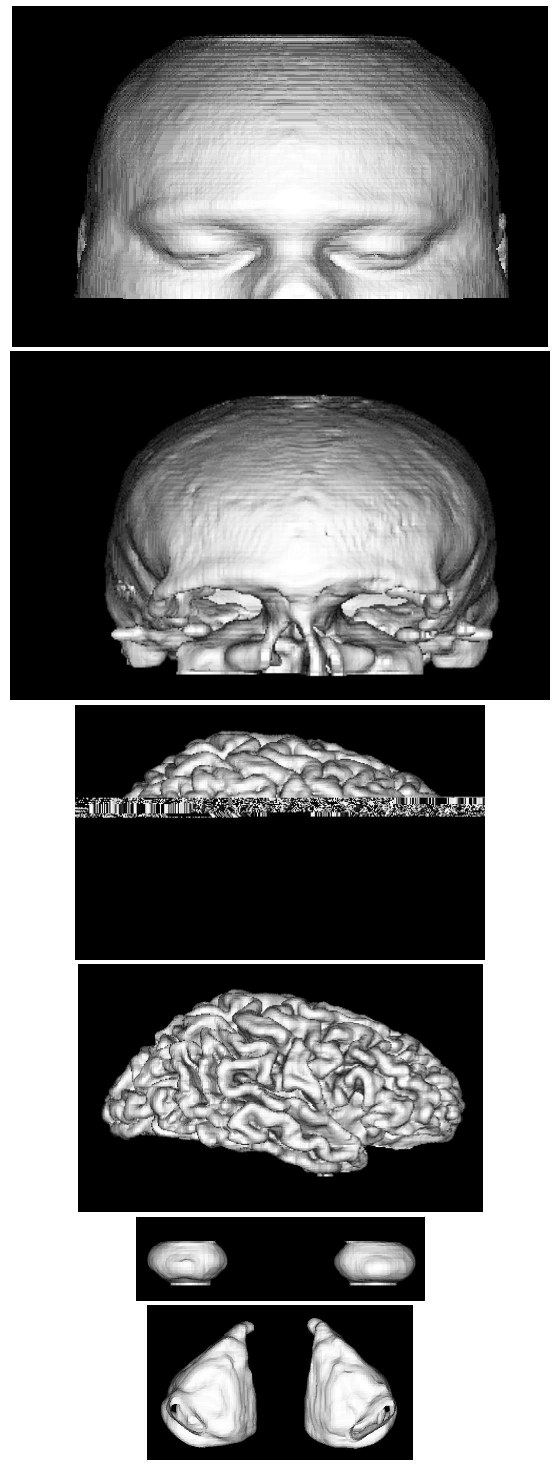

Figure 2: Segmentation Results (Top to Bottom) Scalp, Skull, Gray Matter, White Matter, Eyeballs, Eye and fat tissue.

III. Mesh Generation

In order to solve the forward problems, the geometrical information should be converted into a numerical form (mesh). This section presents the applied mesh generation algorithm for BEM. The algorithm used in mesh generation is shown in Fig. 2.

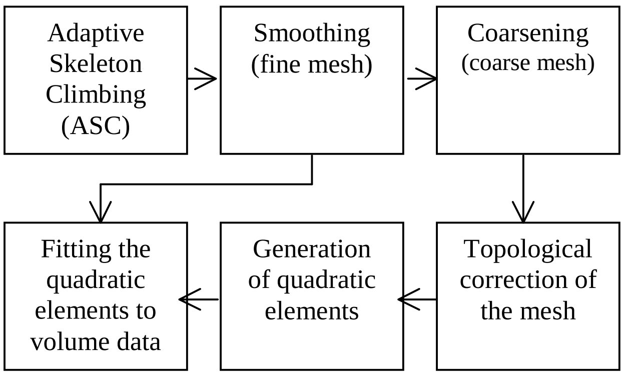

Figure 2 : The algorithm used in mesh generation

The adaptive skeleton climbing (ASC) algorithm is used to triangulate the volume data at a given threshold. The algorithm places one or more triangles to each boundary voxel and can generate 4 to 25 times fewer triangles than that generated by marching cubes algorithm.

Smoothing is a surface signal low-pass filter algorithm. It suppresses the high frequencies caused by noise and the slices of the MR images. The vertices of the polyhedral surface are moved without changing the connectivity of faces. Number of vertices and faces are preserved.

In coarsening, an error is calculated at each node with respect to the Delaunay criteria. At every step of coarsening the node pair with lowest errors are connected together and the coarse mesh is obtained.

The resulting mesh, after triangulation and coarsening, may contain some undesirable topological artefacts, such as disconnected or multiply connected components and singular nodes. These are corrected after the coarsening step to create a single manifold surface that represents a given boundary.

Using the resulting linear mesh nodes are added at each mid point of every edge and these points are placed to fit the original fine mesh to create quadratic elements that match the volume data.

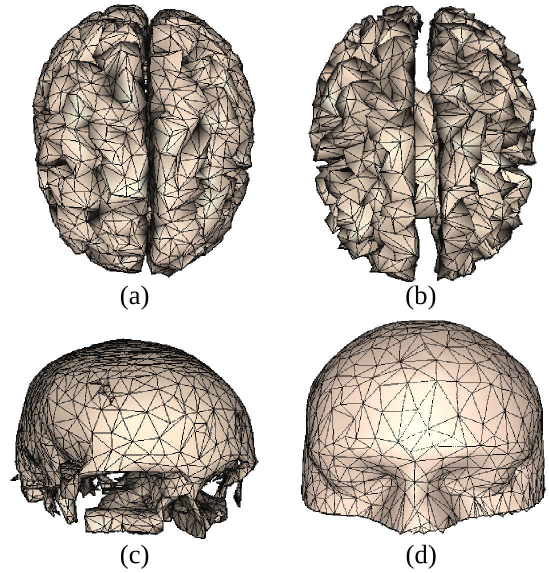

Figure 3 : The meshes generated for (a) cortex with 5000 elements, (b) white matter with 5000 triangles, (c) skull with 5000 triangles and (d) scalp with 2000 triangles.

In previous BEM studies, the boundaries are represented as closed, non-intersecting surfaces. However, to obtain realistic head models, the eyes should also be included in the model. When the eyes are included, the skull-CSF and the skull-scalp interfaces cannot be taken as closed interfaces. In that case, skull-eye, skull-scalp, skull-CSF, eye-scalp, eye-CSF interfaces occur. Work is in progress on creating such a realistic mesh using a mesh intersection algorithm based on [10]

IV. Results

In this work segmentation is applied to the axial MR images with 60 slices, 3 mm thickness [11]. The skull and sinus regions are assumed to have the same electrical properties. Consequently, they are segmented as the same tissue type.

The results of the segmentation are compared with other results in the literature. It is observed that the major folds of the brain are followed successfully. Operator-assisted segmentation of a brain volume from T1 and PD images take about 40 minutes using tools created in MATLAB. The boundary mesh generation (triangulation, smoothing, coarsening, and correction) takes about 10 minutes for each boundary on a Pentium II 300MHz computer.

The resulting five layer mesh contains 12000 nodes, which can be solved on a powerful workstation with 2Gbytes of memory.

V. CONCLUSION

In this study, the segmentation and mesh generation algorithms are explained. Meshes created for cortex, white matter, scalp and skull are presented. With the inclusion of the eyes into the mesh, a BEM model will be obtained that can realistically model the geometry and conductivity distribution of the head.

REFERENCES

[1] N. B. Cuffin, D. Cohen, “Magnetic Fields of a dipole in special volume conductor shapes,” *IEEE Trans. Biomed. Eng*., Vol. 24, No. 4, 372-381, 1977.

[2] S. Ueno, K. Iramina, K. Harada, “Effects of inhomogeneities in cerebral modeling for magneto-encephalography,” *IEEE Trans. Magn*., vol. 23, 3753-3755, 1987.

[3] N. B. Cuffin, “EEG Localization accuracy improvements using realsitically shaped head models,” *IEEE Trans. Biomed. Eng*., vol. 43, no. 3, 299-303, 1996.

[4] Z. Akalın, N. G. Gençer, “MR Kafa Görüntülerinin bölütlenmesi”, *Biyomedikal Mühendisliği Ulusal Toplantısı Bildiriler Kitabı*, 138, İstanbul, 2000.

[5] T. Poston, T. Wong, P. Heng, “Multiresolution isosurface Extraction with Adaptive Skeleton Climbing”, *Eurographics ‘98*, vol.17, no: 3, 1998.

[6] G. Taubin, “A Signal Processing Approach to Fair Surface Design,” *Siggraph’95*, 1995.

[7] M. Garland, P. Heckbert, “Surface Simplification Using Quadratic Error Metrics,” *Proc. of Siggraph*, pp. 209-216, 1997.

[8] A. Gueziec, G. Taubin, F. Lazarus, W. Horn, “Converting Sets of Polygons to Manifold Surfaces by Cutting and Stitching,” *IEEE Visualization ‘98*, pp. 383-390, 1998.

[9] N. G. Gençer, I. O. Tanzer, “Forward problem solution of electromagnetic source imaging using a new BEM formulation with high-order elements,” *Phys. Med. Biol*., 44, pp. 2275-2287, 1999.

[10] S. H. Lo, “Automatic mesh generation over intersecting surfaces,” *Int. J. for Numer. Methods in Eng*., vol. 38, 943-954, 1995.

[11] “Brain Web: Simulated Brain Database”, internet address: *http://www.bic.mni.mcgill.ca/brainweb*.