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Image Based-Mesh Generation for Realistic Simulation of the Transcranial Current Stimulation

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Introduction

Electrical stimulation of the brain involves the application of currents delivered through scalp electrodes to modulate brain activity, known as Transcranial Current Stimulation (TCS). A critical factor for TCS efficacy and safety is the "spatial focality" of induced neuronal modulation. Bikson and co-authors from the City College of New York have been investigating the impact of disc electrode configuration using computational modelling techniques. A range of configurations such as distant-bipolar, adjacent-bipolar, ring-belt, concentric ring and double concentric ring were simulated using COMSOL Multiphysics - applying Laplace Equation on a rather simplified geometrical representation of the human head (i.e. four concentric spheres representing: brain tissue, cerebrospinal fluid, skull and the scalp respectively) [1]. More recent collaboration between CCNY and Simpleware Ltd has taken this research into another level by introducing more realistic geometry built based on high resolution MRI scan images (1 mm x 1 mm x 1mm spacing) using Simpleware's Image-Based Meshing tools [2].

This paper will discuss the comprehensive solution adopted for converting the 3D digital/medical images directly into the computational model. An extensive set of tools for image processing and data segmentation with a unique algorithm for multi-part marching cubes supported by a special multi-part smoothing technique will be presented. The workflow using Simpleware Software (namely ScanIP and +ScanFE) will be illustrated including the option for directly exporting fully compatible models to COMSOL Multiphysics (i.e. using *.mphtxt file format). The extra functionality that allows introduction, positioning and integration of the electrodes (represented originally in a standard CAD format – e.g. IGES or STL) into the scan-image will also be presented (i.e. +ScanCAD). Figure 1 shows a typical screenshot of ScanIP with the human head model (brain, CSF, skull and scalp) with a part of the integrated electrode.

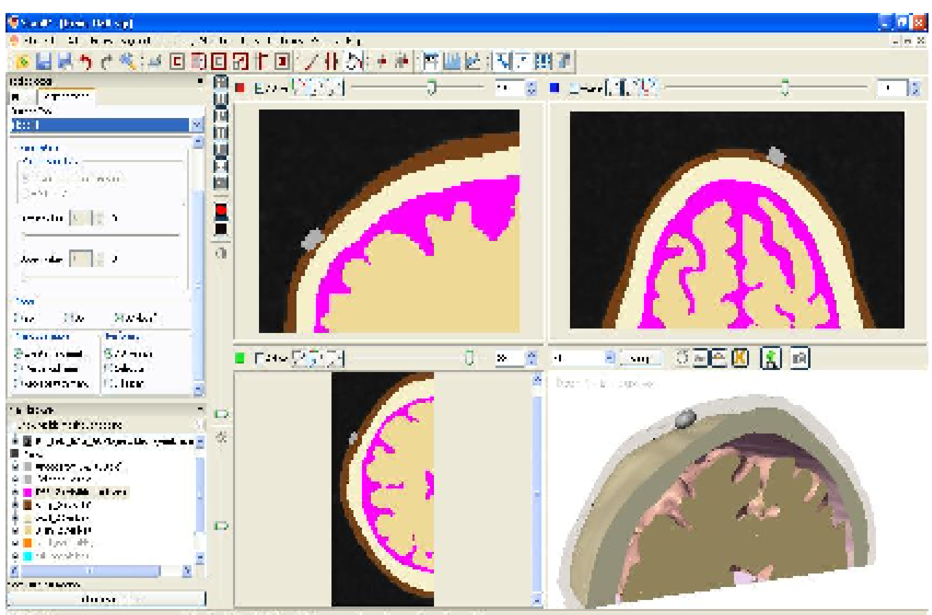

Figure 1, Snapshot of ScanIP – a model of 5 different masks: brain, CSF, skull, scalp and the electrode.

Use of COMSOL Multiphysics

After importing the volumetric multi-domain mesh of the human head with the electrode (4 X 1 ring configuration); see Figure 2, the Laplace Equation $\nabla.(\sigma\nabla V)=0$ (V: potential; σ: conductivity) was solved. The boundary conditions used were (1) inward current flow = J_n (normal current density) applied to the distal surface of the anode electrode, (2) ground applied to the distal surface of the cathode electrode(s) and (3) all other external surfaces treated as insulated. The Conductive media DC application mode was used. The electrical conductivities of the four layers of the model were assigned values taken from standard sources. The electrodes were modeled as conductors with the conductivity of copper.

(a) (b) (c)

Figure 2. Snapshots of the FE model: surfaced mesh of brain tissue (a), cross section in multi-domain volume mesh (b) and an electrode configuration (4 X 1 ring) with scalp surface mesh (c)

Expected Results

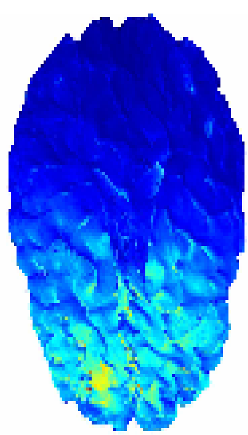

Figure 3. Cortical (brain) surface magnitude plot of induced electric field for Distant Bipolar configuration

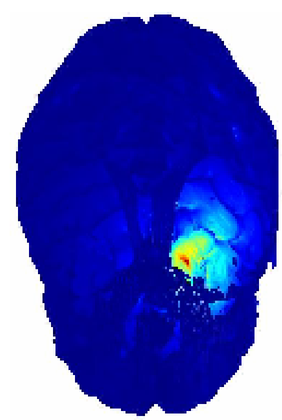

Figure 4. Cortical (brain) surface magnitude plot of induced electric field for 4 X 1 ring configuration

The novel (4 X 1) ring configuration leads to significant increases in spatial focality at the expense of increased scalp surface current compared to commonly used clinical configurations.

Conclusion

Simulation of TCS using realistic geometrical representation is already showing very promising results which can be considered as major step towards the development of a system for patient-specific design of TCS protocols. Accurate patient-specific computational models can be built and superficial cortical regions can be selectively targeted using a 4 X 1 system. Optimization of focality must be balanced against increased electrode current density and scalp/skull current (which may not necessarily reflect safety concerns).

References:

1- Abhishek Datta1, Maged Elwassif1, Fortunato Battaglia2 and Marom Bikson1,3. “Transcranial current stimulation focality using disc and ring electrode configurations: FEM analysis” JOURNAL OF NEURAL ENGINEERING; V 5 (2008) 163–174

2- Simpleware Ltd. www.simpleware.com