Noninvasive Conductivity Extraction for High-Resolution EEG Source Localisation

Electroencephalography (EEG) is an indispensable neurological diagnostic tool in terms of the fast time scale, portability and cost efficiency. Improved spatial resolution of EEG measures would greatly benefit multiple clinical and research applications, including stroke, epilepsy and cognitive studies. The recent advances in dense arrays electrode application have made feasible EEG brain imaging for both rapid application and long-term monitoring.[1] It has been shown that reliable inverse solutions can be obtained and dense array sampling (128, 256 and 512 channels) on the scalp can be projected back to the cortex providing a unique opportunity for monitoring brain activity both in space and time (Figure 1). However, the spatial accuracy of EEG will remain limited because i) mostly simplistic models of the human head (like multi-shell spheres) are commonly used in the inverse procedure of back-to-cortex projection, and ii) the regional conductivities of the human head tissues are largely unknown. This is true not only in each measurement case but in general. Several imaging modalities have been proposed so far to quantitatively measure the electrical conductivity of tissue noninvasively, but none of them is free from some limitations and shortcomings. Magnetoacoustic Hall effect imaging[2] relies on propagation of ultrasound into the tissue, and is not quantitative. Magnetic resonance current density imaging[3] requires applying rather high level of external currents to make produced magnetic field contrast visible by MRI. The electrical conductivity tensor of tissue can be quantitatively inferred from the water self-diffusion tensor as measured by diffusion tensor magnetic resonance imaging (DTI).[4] It can be successful in extracting anisotropic conductivities of the brain tissue, but more problematic regards bone (skull) tissues where the water content is much smaller.

The lack of accurate skull conductivity (most resistive tissue) is particularly problematic given the developmental variations in the human skull from infancy through adolescence. Without an accurate forward model of the skull (specifying the volume conduction from cortex to scalp) even advanced inverse efforts cannot achieve precision with EEG data as the error of source localisation due to conductivity uncertainty may reach a few centimetres.[5] Several authors addressed this problem by using the noninvasive electrical impedance tomography (EIT) approach. A similar approach was used by Hoekema et al[6] in the semi in-vivo conductivity measurements of the skull parts temporarily removed during epilepsy surgery, - fitting for only one

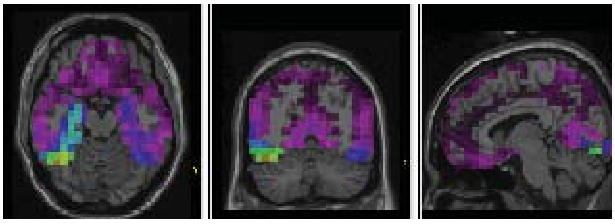

Figure 1: The coloured voxels represent the magnitude of brain activation at the onset of the seizure activity, superimposed on a typical MR image for visualisation.

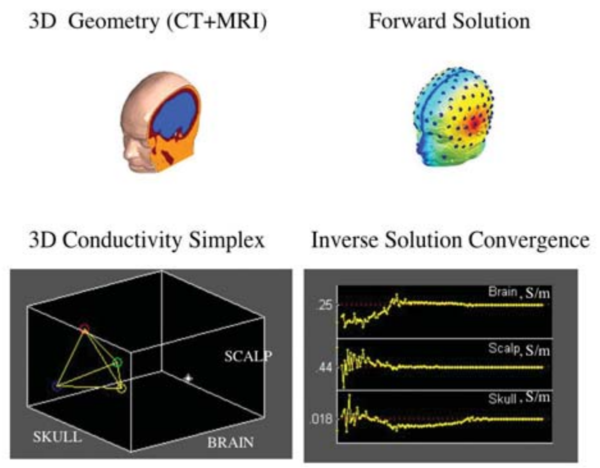

Figure 2: The parameterised EIT procedure: top - 3D subject geometry, CT registered with MRI (left), the forward solution for a particular set of tissues conductivities on the head surface and registered electrodes with EGI Photogrammetry System (right), bottom – initial simplex in the conductivity space (left) and conductivity convergence in the inverse solution (right).

Table 1. Initial and estimated tissues parameters in 4-compartment realistically shaped FD model

Tissue type	*$\sigma(\Omega^{1}m^{1})$ (assumed)*	*$\sigma(\Omega^{1}m^{1})$ (estimated)*	*$\Delta\sigma(\Omega^{1}m^{1})$ (estim. error)*
Brain	*0.25*	*0.2491*	*0.0099*
CSF	*1.79*	*1.7933*	*0.0311*
Skull	*0.018*	*0.0180*	*0.00017*
Scalp	*0.44*	*0.4400*	*0.00024*

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unknown parameter was performed, though. Goncalves et al[7,8] applied spherical and a three-layer boundary element (BEM) models to fit their EIT measurements for six subjects.[9] However, since in such models skull thickness and conductivity are interchangeable to some extent, more accurate geometry representation is needed. Recently we have shown in our group[10,11] that using the parameterised EIT measurements procedure and realistically shaped high-resolution finite difference models (FDM) of the human head based on the subject specific co-registered CT and MRI scans, as is shown in Figure 2, it was possible to extract three and four tissues conductivities (Table 1) both in simulations with synthetic and real experimental data with good accuracy using the multi-start downhill simplex algorithm.[12]

Our current focus is to further improve conductivity information for the benefit of high-resolution EEG source localisation. We are conducting measurements repeatedly on individual subjects to prove the method's robustness and show individual variability of head tissues conductivity across individuals. Electrical Geodesics, Inc. (EGI) has developed a data acquisition system that provides current injection between selected electrode pairs (at very safe current levels) and simultaneous acquisition of return potentials from the dense sensor array of the Geodesic Sensor Net. Our current work will further refine a methodology for constructing accurate forward models of electrical conductance for the human head through incorporating the high-resolution structural details of the human head from MRI/CT scans and providing the non-invasive procedure for estimation of the major tissues conductivity parameters. The latter is based on parameterised EIT inverse solution for the data collected at EGI. In the next stage of the project, a refined forward solver will incorporate anisotropies of the head tissues, in particular skull and white matter. The advanced simulation annealing algorithm has been proved to show better performance in the inverse procedure in terms of finding the global minima of the cost function with larger number of unknowns. This will allow us to extend the procedure to a parcellated skull (10-12 anatomically relevant bone plates) and include the skull conductivity inhomogeneities information into the forward solver for the EEG inverse problem. These tasks require extensive computational resources. At Neuroinformatics Center, University of Oregon we have access to a multi-cluster (SGI, Dell, IBM p650; IBM p690; IBM BladeServer) high performance parallel computing system dedicated to analysis of human EEG and MEG data. The first and primary application of these computing resources is to solve the conductivity problem of the human head.

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