Forward Problem Solution Using the Finite-difference Time-domain method combined with Frequency Scaling

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INTRODUCTION: The estimation of sources underlying measured MEG and EEG signals requires an accurate solution of the static approximation of Maxwell's equations that can be conveniently expressed as the lead field [1], which is the sensitivity distribution of a given MEG sensor or an EEG electrode. In the present state-of-the art approach for lead field estimation (Boundary Element Method, BEM) [2] the head is described with a few compartments with constant and isotropic electrical conductivity. Arbitrary, anisotropic conductivity distributions can be handled with the finite-element and finite-difference methods. This allows taking into consideration thin and highly conductive tissues such as bone marrow, disregarded when using the BEM. We propose a new approach for the lead field computation using the cell-oriented finite-difference time-domain (FDTD) method combined with the frequency scaling technique [3] for low frequencies.

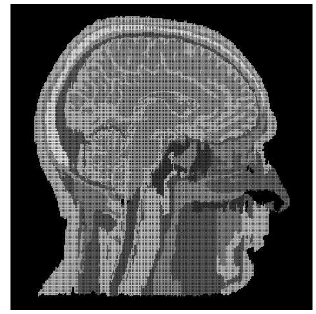

Figure 1: Anatomically accurate $1\times1\times1\,\text{mm}^3$ resolution head model used for induced currents simulations.

METHODS:

Head Model and Electrode Locations: One 29-tissue high-resolution ($1\,\text{mm}^3$) head model (Fig. 1) segmented from the anatomical MRI data was used (a $6\,\text{mm}^3$ resolution was used here). The tissue conductivities were selected according to the literature [4].

We computed the lead field from 32 electrode locations (digitized from a real EEG recording) on this particular subject which we co-registered to the head model and used the 33^{rd} electrode near the vertex (Cz) as a reference.

Lead Field Computation: The reciprocity theorem states that the lead field of a given electrode pair is the same as the current pattern generated in the underlying conductor by feeding a unit current through the electrodes. Therefore, we were able to apply the FDTD method to calculate induced current densities using XFDTD software (REMCOM Co.). For dramatical reduction of computational time, simulations at target frequency $f = 20\,\text{Hz}$ were initially performed at a higher frequency $f' = 20\,\text{MHz}$ and then scaled, $J(f) = (f/f')J(f')$, according to the frequency scaling technique [3].

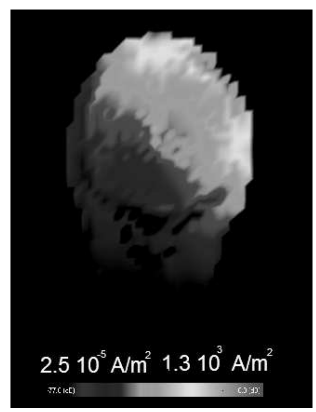

Figure 2: Induced current densities computed after connecting Cz and T8 positions with a current source of 1 A.

RESULTS-CONCLUSIONS: The comparison of the results from the FDTD computation with those given by a three-compartment boundary-element model showed that the lead field distributions are qualitatively similar. The computation of the lead field for one electrode pair took about 80 minutes on a 2-processor desktop computer (Intel XEON 2.8 GHz, 2 GB RAM).

FDTD can incorporate an arbitrary conductivity distribution and anisotropy without the need of complex meshing techniques typically needed in the finite-element and BEM approaches.

REFERENCES

1. Wolters, C. H., et al., *Inverse Problems*, Institute of Physics Publishing, Vol. 20, 1099–1116, 2004.
2. Oostendorp, T. F., et al., *IEEE Trans. on Biomed. Eng.*, Vol. 36, No. 3, 382–391, 1989.
3. Moerloose, J., et al., *Radio Science*, Vol. 32, No. 2, 329–341, 1997.
4. Gabriel, C., Brooks Air Force Technical Report AL/OE-TR-1996-0037.