INTRODUCTION: PHYSICS OF EEG/MEG

Fundamental problems in electroencephalography (EEG) and magnetoencephalography (MEG), in particular, source localization and impedance imaging require modeling and solving the associated boundary value problems on a fine grid. The relevant frequency spectrum in EEG/MEG is typically below 1 kHz, and most studies deal with frequencies between 1 and 100 Hz, therefore, the physics of EEG/MEG can be well described by the quasi-static approximation of Maxwell’s equations:

The forward problem can be stated as follows: given positions, orientations and magnitudes of dipole current sources, as well as geometry and electrical conductivity of the head volume, to calculate the distribution of the electrical potential on the surface of the head (Eq. (1)) or intensity of the macroscopic magnetic field (Eq. (2)).

Having defined potentials and current distribution, one can calculate the magnetic field it can be found through the Biot-Laplace law.

The inverse problem implies fitting the computed and measured data to extract information on, locations of the sources or the internal head tissue properties and usually involves the large number of runs for the forward problem. This is why the computational methods for the forward problem which are stable, fast and eligible for parallelization are of great interest.

The main idea behind the FE or FD methods is to reduce a continuous problem with the domain into elements.

The FE method is generally the easiest method to code and implement, but it usually involves the large number of runs for the forward problem. This is why the computational methods for the forward problem which are stable, fast and eligible for parallelization are of great interest.


SUMMARY

- FEMLAB is instrumental as a FE solver and/or a FE mesh generator for 3D phantoms and 2D realistic MRI geometries
- In case of 3D MRI data of the brain the inner structure must be simplified to be imported into FEMLAB
- Finite Difference ADI algorithm [4] has been identified as an appropriate choice for a fast solver in the forward problem

DISCUSSION AND FUTURE RESEARCH

When using FD methods one should be aware about the following “pros” and “cons”:

- Pros:
  - meshes are relatively easy to construct as the cubic/rectangular elements can be “mapped” directly from the voxels of the medical images (3D MRI scans)
  - many anatomical details can be included as the computational load is based on the number of elements and not on the specifics of tissues differentiation.

- Cons:
  - the “native” geometry for FD is rectangular, therefore the simplest way of implementing curved boundaries is to embed the complex object into a computational cubic domain. However, the redundant voxels can bring additional computational cost in terms of accuracy and speed.
  - the number of elements and not on the specifics of tissues differentiation.

Future work will involve refinement and parallel implementation of the FD ADI algorithm based solver for the forward problem with the aim of applications in the EEG/MEG inverse problem and other modalities (such as electrical impedance tomography and NIR diffusive optical tomography). It will include:

- investigation of FDM accuracy and rate of convergence against the benchmark analytical models and FEM algorithms using FEMLAB and other FEM software;
- implementation of a parallel version of the current FORTRAN 77 code in C/C++ to run on computer cluster NEURONIC;
- implementation of a similar FD ADI algorithm for solving the photon migration equation the heterogeneous brain tissues, which is basic in NIRS modalities.

3D cross-section of the 3D Poisson equation solution at 64x64x64 © and 256x256x256): The effective conductivity in the air regions is 0.01% of the average head conductivity. Convergence: ≤ 150 iterations.

Reference