Validating Finite Element Method Based EEG and MEG Forward Computations

Lanfer, Benjamin, Institut für Biomagnetismus und Biosignalanalyse (IBB), Münster, Germany
Wolters, Carsten H., Institut für Biomagnetismus und Biosignalanalyse (IBB), Münster, Germany
Demokritov, Sergej O., Institut für Angewandte Physik, Münster, Germany
Pantev, Christo, Institut für Biomagnetismus und Biosignalanalyse (IBB), Münster, Germany

Abstract

For the accurate reconstruction of current sources in the brain from measured EEG and MEG data accurate forward computations of the electric potentials resp. the magnetic fields are necessary. In complex head volume conductors the simulation of the electric potentials and magnetic fields can be done using the Finite Element Method (FEM).
The task of this work is to study how accurate the forward problem can be solved using FEM. This is done by comparing the numerical solution to an analytical reference solution, which exists for multilayer sphere models. The numerical solution is calculated using two different models for the mathematical dipole: Venant's principle and the subtraction approach.
The results showed, that EEG and MEG can be simulated very accurately for sources at realistic excentricities and for both dipole models using FEM. For realistic volume conductors similar accuracies of the numerical method can be expected.

1 Introduction

For the accurate reconstruction of current sources in the brain from measured EEG and MEG data, accurate forward computations of the electric potentials resp. the magnetic fields are necessary. For complex head volume conductors this simulation of the electric potentials and magnetic fields needs numerical methods. Very interesting is the Finite Element Method (FEM) as it is able to handle arbitrary geometries and inhomogeneous and anisotropic conductivities. At the IBB the software toolbox *IP-NeuroFEM* is developed in which this method is implemented [1]. The task of this work is to study how accurately the forward problem can be solved with FEM. This is done by comparing the numerical solution to an analytical reference solution, which exists for multilayer-sphere models.

2 Materials and Methods

2.1 The Sphere Model

The EEG and MEG forward computations were performed for a 3-layer sphere model. The spheres have radii of 92 mm, 86 mm and 80 mm. The conductivities of the compartments are 0.33 S/m, 0.0042 S/m and 0.33 S/m resp..
The EEG was simulated at 134 electrodes, distributed on the surface of the model in a very regular way. The MEG was simulated for 2 sets of 258 magnetometers each. The positions of the centres were distributed in a very regular way on a concentric sphere. The magnetometers are radially oriented for the first set and tangentially for the second set of sensors.
The potentials and fields were computed for dipoles at 79 positions from the centre of the spheres in steps of 1mm along the z-axis. By definition the highest dipole has an excentricity of 1.0. For the EEG the potentials were computed for radial and tangential, for the MEG only for tangential dipoles.
With the software CURRY [2] tetrahedra meshes and with VGRID [1] regular cube meshes, both with an average element width of 2 mm and approx. 400 000 nodes, were built.

2.2 The Error Measures

For the validation of our numerical solution the FEM results were compared to the analytical solution for a multilayer sphere [3,4]. Therefore two different error measures were employed.
The first measure is the *relative difference measure, RDM* [5]. It describes the difference in the topography between the analytical and numerical solution. The best value of the RDM is 0.
The second measure is the *magnification error, MAG* [5]. It indicates differences in the total strength of the potentials resp. fields. The best value of the MAG is 1.

2.3 The Dipole Models

In our study we used two methods for modelling the mathematical dipole: *Venant's principle* [6] and the *subtraction approach* [7].

3 Results

3.1 EEG

For reasonable excentricities, for both dipole directions and for both dipole models the RDM is below 0.05. For highest excentricities the RDM for the subtraction approach gets worse than the error for Venant's approach. This is suspected to be due to a not yet optimal implementation of the method. Better integration already showed to substantially improve results. Similar findings with regard to the EEG have been achieved in [8].

3.2 MEG

Radial magnetometers

The error of the primary flux can always be neglected as it is computed analytically and therefore very accurate. Nearly no difference between Venant's principle and the subtraction approach can be observed for the total flux (**Figure 1**).

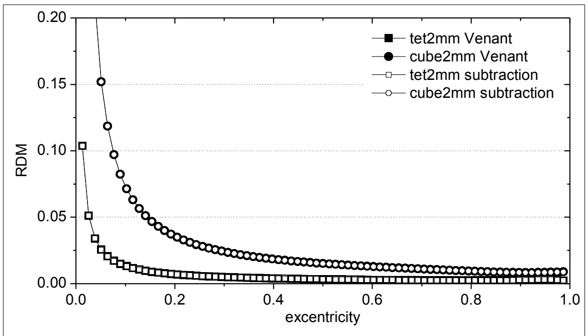

Figure 1 RDM for the total magnetic flux and radial magnetometers.

To lower excentricities the RDM rises, because the error for the secondary magnetic flux gets more important for low excentricities where the strength of the total magnetic flux strongly decays. The MAG for realistic excentricities resides between 0.95 and 1.05.

Tangential magnetometers

Here volume currents in a sphere have a significant contribution to the total magnetic flux. The RDM for the secondary magnetic flux is always below 0.03.

In the error curves of the Venant approach large oscillations are noticeable, because the accuracy of Venant's approach depends on the position of the current dipole relative to the next node of the mesh.

It can be observed that the subtraction approach is more accurate than the Venant approach.

For the total magnetic flux (**Figure 2**) the subtraction approach gives excellent results. Again, for lower excentricities, the errors of the secondary magnetic flux get more important. The MAG for realistic excentricities resides between 0.90 and 1.05.

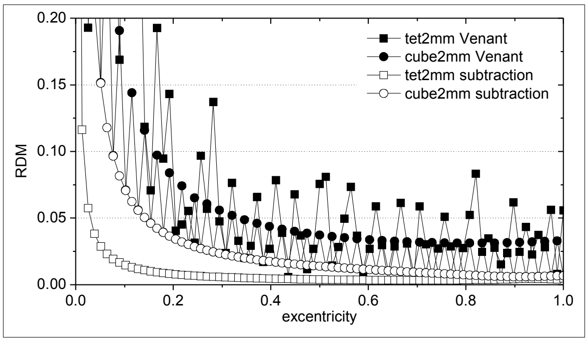

Figure 2 RDM for the total magnetic flux and tangential magnetometers.

4. Discussion

In this study it was shown that the forward problem for the EEG and the MEG can be accurately solved using the Finite Element Method. Furthermore the presented results indicate that very high accuracies for both radial and tangential magnetometers are achieved by using the subtraction approach.

It was proven in [7] that similar accuracies can be expected for realistic models of the human head. In future studies we will focus our interest on using FEM for modeling realistic volume conductors with regard to the inverse EEG and MEG problem.

5. References

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