Reciprocity Basis for EEG Source Imaging

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Introduction

In recent years, significant progress has been made in the area of EEG/MEG source imaging. Source imaging using simple spherical models has become increasingly efficient, with consistently reported accuracy of within 5mm. In contrast, source localization on realistic head models remains comparatively modest, with sub-centimeter accuracy being the exception rather than the norm. A primary reason for this discrepancy is that most source imaging techniques are based on lead-field theory. While the lead-field for simplified geometries can be easily computed analytically, an efficient method for computing lead-fields for realistic geometries has, until now, remained elusive. In this paper, we propose an efficient method for computing realistic EEG finite element lead-field basis.

Background

The distribution of an electromagnetic field in the head is described by the linear Poisson equation. From this, it follows that the projection from current sources at discrete locations to potential measurements at discrete recording sites on the scalp can be represented by a so called lead-field matrix, L [1]. Each source location requires a computation of the potential field on the electrodes due to it.

While fast analytic expressions exist for the computation of potentials in spherical models, these solutions cannot be applied to realistic head models. Rather, a complete forward numerical solution must be computed due to each source. We choose to use finite element method (FEM) to generate these forward solutions [4]. FEM is not only capable of representing the complex boundaries and inhomogeneous regions of realistic models, but can also capture anisotropic conductivities of the domain. When used on realistic head model (3mm resolution), FEM require upwards of a minute of CPU time to solve a forward simulation on an SGI MIPS R10000 processor. Because of this computational expense, it seems feasible to build a lead-field for only a very sparse grid of sources. Even a 16^3 grid (12mm resolution), for example, with three orthogonal dipole components per cell, would require over a day of continuous computation to build L.

Below, we introduce a novel method for constructing the lead-field matrix L. Using this method, we are able to construct the L matrix for a head model with 3mm cell resolution (64^3 grid) in under 10 minutes.

Methods

For our basis, we will still be considering three orthogonal dipole sources per cell, but the shape and distribution of our cells will be different than the traditional configuration. Rather than placing sources on a regular grid, we have chosen to use the unstructured set of tetrahedral cells from our underlying finite element mesh, which gives us the maximal possible resolution for that mesh. We also take advantage of FEM computing the potentials through the entire volume. This is all can be done by using the principle of reciprocity [3].

Rather than placing a source in every element and compute a forward solution, we “invert” this process: we place a source and sink at pairs of electrodes and for each pair compute the resulting electric field in all of the elements. We then use the reciprocity principle to reconstruct the potential differences at the electrodes for a source placed in any element. Repeating the above procedure for every electrode pair we construct an element-oriented lead-field basis that maps dipole components placed at the elements to potentials at the scalp-recording electrodes.

Simulations

To verify the accuracy and usability of the basis, we constructed a realistic finite element head model from a volume MRI scan. The model contains approximately 320,000 elements, 60,000 nodes and six different conductivity regions. Using our method, we first computed the reciprocity L basis which required 9 minutes of CPU time. We then used the basis to construct and visualize a single dipole cost-function field, i.e. misfit between the measured data and the sequence of forward solutions. The minimum of this field corresponds to the optimal dipole position for a single dipole model.

If the goal is not to compute this field everywhere in the volume, but just to perform a source localization, we can use a simple search technique such as downhill simplex and evaluate just those locations along a search path. For our model, this reduced the number of cost-function evaluations from 100,000 to 230, resulting in a source localization which was achieved in less than 5 seconds.

All the computations and visualization for this paper were performed within the SCIRun problem solving environment [2].

References

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