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OpenMEEG for M/EEG forward modeling: a comparison study



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Objective

Evaluate the accuracy of available BEM solvers for M/EEG forward modeling with realistic head models.

The M/EEG forward problem

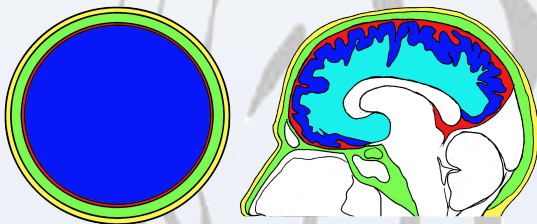
Objective

Predict what is measured by M/EEG sensors due to a configuration of current generators within the head.

Challenge

Analytical solutions exist for simple models such as sphere models. With realistic head models, numerical solvers are required. BEM solvers are adapted to models with piecewise constant conductivities.

Sphere models vs. realistic models



Why compare BEM solvers?

- BEM solvers are based on different mathematical formulations.
- For a given formulation, implementation details vary:
 - Galerkin methods vs collocation methods
 - Precision in numerical integrations
 - Adaptive vs. non adaptive integration procedures

Experimental setting

Software packages tested

- OpenMEEG with and without adaptive integration (OM and OMNA) [1,2,3]: Symmetric BEM with P1-P0 elements.
- BEMCP (CP) [Phillips 00]: standard BEM with linear collocation (LC)
- Simbio (SB) [Zanow et al. 95]: std. BEM with LC + ISA
- Dipoli (DP) [Oostendorp et al. 89]: std. BEM with LC + ISA
- Helsinki BEM [Stenroos et al. 07]: LC (HB) and LC + ISA (HBI)

Model considered

- 3 nested shells: inner skull, outer skull and skin surfaces (radii 88, 92, 100).
- 5 dipoles at different distances from the inner skull: direction (1, 0, 1)
- regular and random meshes
- a random mesh with N vertices is obtained by meshing the convex hull of $10N$ points randomly sampled on the unit sphere followed by decimation.

Simulation study: Comparison results for EEG

Precision measures

- Numerical solution g_n
- Analytical solution g_a
- Relative Difference Measure (RDM):

$$RDM(g_n, g_a) = \left\| \frac{g_n}{\|g_n\|} - \frac{g_a}{\|g_a\|} \right\|$$

Should be close to 0

- Magnitude (MAG):

$$MAG(g_n, g_a) = \|g_n\| / \|g_a\|$$

Should be close to 1

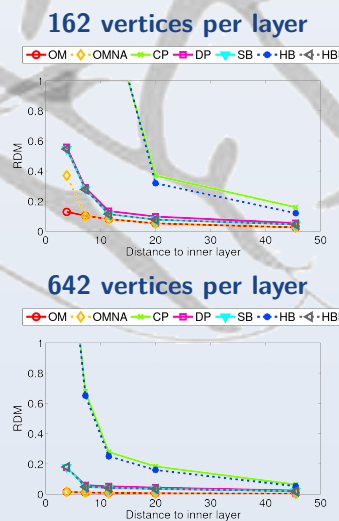
- With random meshes RDMs and MAGs are computed with 100 repetitions of the experiment.

- Note: MEG accuracy relies on EEG solutions via the Biot et Savart law

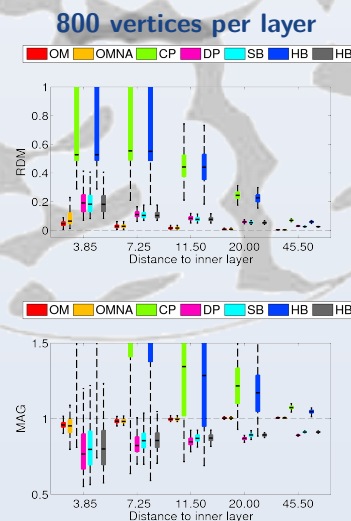
Technical details

- OpenMEEG is open source (Linux, Windows, Mac OS X)
- OpenMEEG is written in C++ and can be used from Python and Matlab using the Fieldtrip toolbox
- Experiments have been performed with Fieldtrip
- <http://openmeeg.gforge.inria.fr>
- openmeeg-info@lists.gforge.inria.fr

With standard meshes



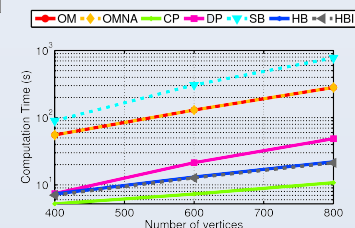
With random meshes



OpenMEEG is the most accurate solver with regular meshes.

OpenMEEG with adaptive integration is the most robust to imperfect meshing.

Computation times



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- Kybic J., Clerc M., Abboud T., Faugeras O., Keriven R., Papadopoulos T. A Common Formalism for the Integral Formulations of the Forward EEG Problem, IEEE Transactions on Medical Imaging, 2005