**BEM-FMM toolkit with adaptive mesh pre-refinement (*b*-refinement) for EEG forward modeling**

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**Introduction**

This toolkit augments a fast-multipole-method-accelerated boundary element method (BEM-FMM) [1][2] by adaptive mesh pre-refinement (*b-*refinement) [3] to accurately solve an EEG forward modeling problem on a realistic head model with approximately 1 M facets. On standard server hardware (3 GHz CPU), the solution can typically be obtained in just over 1 minute. AMR increases the model size by 10% to 15%. For a detailed explanation of the method and accuracy benchmarks, please see [3]. If you use this toolkit in your research, please also cite [3].

This toolkit is made available under GNU GPLv3.

To function, this toolkit requires MATLAB R2023a or newer with the Parallel Computing Toolbox and the Statistics and Machine Learning Toolbox. Scripts are to be executed *sequentially*, without clearing the MATLAB workspace in between.

**Quick Start Guide – Spherical Shell Model**

1. Download the contents of the GitHub repository to the local machine
2. Open MATLAB to Example01\_Spheres
3. Set up the model and cortical dipole excitation by executing bem0\_setup\_base\_model.m and bem1\_setup\_dipole.m.
4. Prerefine the model and observe the refined spherical shells by executing bem2\_setup\_admeshref.m. Then close all figures.
5. Execute bem2\_setup\_integrals.m to precompute required model self-interaction integrals
6. Execute bem3\_define\_planes.m to view cross-sections of the assembled model
7. Execute bem4\_charge\_engine.m to iteratively solve the system for the given dipole source
8. Execute bem5\_surface\_field\_c.m to view the charge density on the outermost shell. The selected shell may be changed by setting the variable tissue\_to\_plot to “Skull”, “CSF”, or “GM”.
9. Execute bem5\_surface\_field\_p.m to view the potential on the outermost shell. The selected shell may be changed in the same manner as previously.

To obtain a solution using the base spherical shell model without adaptive b-refinement, follow the same process but exclude (4).

**Quick Start Guide – Realistic Head Models**

1. Download the contents of the GitHub repository to the local machine
2. Open MATLAB to either Example02\_Connectome110411 or Example03\_Connectome122620.
3. Construct and prerefine the head model by:
   1. Changing MATLAB’s working directory to the “Model” subfolder
   2. Executing model1\_setup\_base\_model.m
   3. Executing model2\_add\_AMR.m.
4. Change the working directory to the main folder
5. Execute bem1\_setup\_solution.m to initialize parameters for the integrals and solver
6. Compute head model self-interaction integrals by executing bem2\_setup\_integrals.m.
7. Solve the forward problem by executing bem3\_charge\_engine.m
8. Observe fields on the scalp surface by executing:
   1. bem3\_surface\_field\_b.m for the magnetic field
   2. bem3\_surface\_field\_c.m for the charge density distribution
   3. bem3\_surface\_field\_p.m for the potential distribution

To obtain a solution using the base 1M facet model without adaptive *b-*refinement, follow the same process but exclude (3c).

**References**

1. Makarov SN, Noetscher GM, Raij T, Nummenmaa A. A Quasi-Static Boundary Element Approach with Fast Multipole Acceleration for High-Resolution Bioelectromagnetic Models. IEEE Trans Biomed Eng. 2018 Mar 7. doi: 10.1109/TBME.2018.2813261.
2. Makarov SN, Hamalainen M, Okada Y, Noetscher GM, Ahveninen J, Nummenmaa A. Boundary Element Fast Multipole Method for Enhanced Modeling of Neurophysiological Recordings. IEEE Trans Biomed Eng. 2021 Jan;68(1):308-318. doi: 10.1109/TBME.2020.2999271.
3. (Awaiting publication)