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].

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:
    a. Changing MATLAB's working directory to the "Model" subfolder
    b. Executing model1_setup_base_model.m
    c. 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:
    a. bem3_surface_field_b.m for the magnetic field
    b. bem3_surface_field_c.m for the charge density distribution
    c. 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)