Computational Bio-Electromagnetism

Fall 2021

Meeting dates: Aug. 23-Dec. 11
Meeting times: T,TH 12:00 PM- 1:15 PM
Location: TBA
Instructor: Luis Gomez
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Office Hours: 1:20 PM- 2:20 PM T and by appointment

Course Prerequisites: Recommended: Electromagnetics (ECE 30411); Familiarity with a computer programming or scripting language (e,g, Python, Matlab, Fortran, C++);

Course Objectives: Gain a deep understanding of computational methodologies used for E-field modeling in non-invasive brain stimulation (NIBS), Electroencephalogram (EEG) and Magnetoencephalogram (MEG).

Course Outcomes: Upon completion of this class you should be able to:

1. determine the limitations of simulation predictions of the electric field by various numerical methods
2. understand papers about computational electric field dosimetry and critically assess their content
3. implement basic differential equation/integral equation numerical electromagnetic codes
4. use existing fMRI software to segment head MRI images into tissue types and generate head models
5. Understand the various methods used by segmentation pipelines like fsl, SPM, and freeSurfer.
6. determine the best tool for a given application and solver parameters

Honor Code: You are encouraged to work together on projects and homework. However, each of you have to turn in your own assignment and if there is considerable collaboration, please write the name of the person you worked with. The tests are to be done independently and any violations will be reported to the University.

Textbooks:

There is no required textbook for this class. Relevant journal articles will be assigned as readings.

Recommended textbooks in order of importance:

Risto Ilmoniemi and Jukka Sarvas, *Brain Signals: physics and mathematics of MEG and EEG*.

Jin, Jian-Ming. *The finite element method in electromagnetics*.

Riitta Hari and Aina Puce, *MEG-EEG Primer*

Homework: 4 assignments including analytical and numerical-based problems.

Course project(s): Mid-term project due Sept 27. oral presentations: Dec.3-10.

- **Modeling project**: The aim of the project is to test your ability at applying the methods discussed in class. It will involve one of the following: implementing a finite-element 2D or Finite-Difference frequency domain code in 3D for Laplace equation operator with zero boundary conditions. Specific details to come. I would like a final report of the project. Specific details TBD.
- **Oral presentation:** A presentation on a paper pertaining to computational E-field dosimetry. I will give you options or you can suggest other papers you would like to present.

Final exam: Will be two hours and 2-6 questions. The majority of the questions will be high level and ability to understand general concepts.

Grading: Assignments 30%, modeling project 20%, class participation 10%, oral presentation 20%, final 20%

Tentative topics covered:

Date	Topic	Due
23-Aug	Class Introduction	
25-Aug	Phenomenological description of NIBS, EEG, and MEG	
27-Aug	Quasi-static approximations in bio-electromagnetics	
30-Aug	Differential equation model of transcranial electrical stimulation (TES) and EEG	
1-Sep	Differential equation model of transcranial magnetic stimulation (TMS)	
3-Sep	Introduction to head models	
6-Sep	No Class	
8-Sep	FDM: discretization of differential operators	**Assignment 1**
10-Sep	FDM: sources used for TES and EEG	
13-Sep	FDM: sources used for TMS	
15-Sep	FEM: triangle meshes and basis functions	
17-Sep	FEM: tetrahedral meshes and basis functions	
20-Sep	FEM: discretization of differential operators	
22-Sep	FEM: sources used for TMS	
24-Sep	FEM: sources for EEG and TES	
27-Sep	FEM: advanced sources for EEG and TES	**Project 1**
29-Sep	BEM: Double layer potential	
1-Oct	BEM: Double layer potential II	
4-Oct	BEM: Magnetic sources	
6-Oct	BEM: Electric sources	
8-Oct	BEM: Reciprocity for MEG analysis	
11-Oct	BEM: Single layer potential for TES/EEG	

13-Oct	Segmentation: Expectation maximization methods of FSL	**Assignment 2**
15-Oct	Segmentation: Expectation maximization methods of SPM	
18-Oct	Segmentation: Freesurfer heuristics and region growing methods	
20-Oct	Segmentation: Current trends and the U-Net deep learning automatic segmentation architecture	
22-Oct	Head model generation practical considerations I	
25-Oct	Head model generation practical considerations II	**Assignment 3**
27-Oct	Numerical Method Implementation: Sparse matrix representations	
29-Oct	Numerical Method Implementation: Iterative solvers and basics of preconditioning	
1-Nov	Numerical Method Implementation: Fast multipole methods and the NYU library	
3-Nov	Sources of error in E-field modeling I	
5-Nov	Sources of error in E-field modeling II	**Assignment 4**
8-Nov	Numerical accuracy for TMS analysis I	
10-Nov	Numerical accuracy for TMS analysis II	
12-Nov	Uncertainty quantification for TMS analysis I	
15-Nov	Uncertainty quantification for TMS analysis II	
17-Nov	Uncertainty quantification for TMS analysis III	
19-Nov	Interpreting and processing of EEG and MEG data 1	
22-Nov	Interpreting and processing of EEG and MEG data II	
24-Nov	No Class	
26-Nov	No Class	
29-Nov	Independent work on final project	
1-Dec	Independent work on final project	
3-Dec	Final Presentations	
6-Dec	Final Presentations	
8-Dec	Final Presentations	
10-Dec	Final Presentations	