



School of Electronic Engineering

CB54: Machine Learning Algorithms for EM Wave Scattering Problems

Project Research Log

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Please read before making entries in this log

The purpose of this Project Research Log is to capture concise, focused summaries of research materials you read, as you progress through your project. The emphasis is to record (i) how the material you have read will determine or influence your project solution approach and (ii) your assessment of the key strengths and weaknesses of the solutions, methods, technologies, etc. proposed in the material you have read.

In the first stage of your project, the literature review, use the Log to capture this information for the key papers you have read (for example, the three most important papers of your 10 literature review references). As your project progresses into the design and implementation phases, you will need to continue to search the literature so you can review, revise and refine your initial thinking and the details of your approach to a project solution. Use this Research Log to capture your continued research reading and its influence on your project design and implementation.

Be selective about what you record in this log. Do not use it as an informal notebook while you are reading a new paper. Only make an entry after you have read a paper that you consider important to the development of your project solution. It is expected that, by the end of the project, you will have made between 10 and 20 entries (20 maximum). Share your log with your supervisor for viewing throughout the project. You will submit the final version of the log for grading, at the end of the project implementation period. It will be assessed on the basis of how well you have used your analysis of the literature to inform your project design, implementation and the evaluation of your project results. The Research Log contributes 5% to the overall project mark.

Note: All entries you make in this log must use the prescribed format shown on the next page. You will maintain other notes as you progress through your project but they should not be recorded here. Fill in the details where the *** signs are.

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Statement of project problem / research question (maximum 200 words)

This statement should be periodically reviewed and updated, as necessary, as your project progresses and you gain further insight into the detailed project challenges, requirements and objectives as your project work moves from background reading, literature review, initial project design planning and detailed design and implementation. Initially, start by stating your current understanding of the project objectives. After each meeting with your supervisor, review and refine your project problem statement, as required.

THIS IS JUST TO RECORD THE INITIAL PROJECT STARTING POINT

“When an electromagnetic wave encounters an object it scatters, with some energy being transmitted into the object and the rest propagating in a variety of directions depending on the material composition and local geometry. A precise knowledge of the scattering phenomenon is desirable for a variety of applications, such as medical imaging, radar and wireless communications. Numerical techniques such as the method of moments give highly accurate results, but are computationally expensive. An emerging alternative is the use of machine learning tools that can be trained using a training set of data covering a sufficiently wide feature set (i.e. problem geometry, material, frequency etc). This project will use an in-house, Matlab-based, implementation of the method of moments to train an artificial neural network to solve the problem of EM scattering from convex dielectric bodies.”

A complete reference for the paper

Summary of paper (maximum 100 words)

How is this paper relevant to solving your project problem or addressing your research question?
(maximum 100 words)

What are the strengths and weaknesses of the solutions/methods/technologies proposed in this paper? (maximum 100 words)

Log Entry 01: 2023/05/16

Statement of project problem / research question (maximum 200 words)

"Can the manner in which deep learning has been shown to solve two-dimensional, forward electromagnetic scattering problems applied to the problem of predicting EM wave propagation over rural terrain, namely emulation, be expanded or improved upon?"

As already reported in the Literature Review, various sources have described using deep learning to tackle forward electromagnetic scattering problems, however, to the knowledge of the student, none have provided a public, reproducible, open-source workflow or a model to the research community. The student proposes to approach the integration of the developed deep learning model, Prescient2DL, into SolverEMF2 through the use of Prescient2DL to generate initial guesses for the Krylov Iterative Solver. By establishing the SolverEMF2 workflow, this primary research question will be approached through the investigation of simulations with several segmented statistical hypothesis tests in lieu of qualitative mathematical proofs. Implicitly, the primary aim of the project is to implement a solver with a deep learning model that optimally shifts calculation metrics to towards the lower left corner of the Residual Error versus Iterations/Time graph when solving permittivity contrast source only Volume Electric Field Integral Equations.

A complete reference for the paper

[1] , please refer to the final bibliography.

Summary of paper (maximum 100 words)

This is a new book (2022) dealing with the application of deep learning to electromagnetic problems that the student did not know existed until 2023/05/08 well after the literature review was submitted. The student has read the relevant chapters 1, 2 and 13 of this book and it conforms with the student's literature review with strong overlaps in the references covered. The student views this as an independent confirmation that their research to date and literature review reflects much of the current research energy in the project domain.

How is this paper relevant to solving your project problem or addressing your research question? (maximum 100 words)

In Chapter 13 there is a section dealing with the pros and cons of using DL in the domain whose synthesis would be helpful in the final project portfolio.

Chapter 13 also raises some problems that may be faced in the project. There is a lack of transparency and understanding of the inner workings of the DL architectures. The student believes there are developments in ML space that are working on reducing this lack of transparency, for example, Professor Paul Whelan's visualization methodology for the various layers in the Computer Vision module assignment and the student's understanding that a recent new research domain of explainability in DL may have yielded recent breakthroughs.

What are the strengths and weaknesses of the solutions/methods/technologies proposed in this paper? (maximum 100 words)

One difference to the literature review was that there seems to be a greater consideration given to the sub-algorithmic approaches (references 126-130) that the student had partially avoided. As a result the student may reconsider these approaches and consider their inclusion. The sources not previously considered in the literature review have been recorded in the student's Zotero database for future consideration. In terms of downsides of the book, there was nothing that the student hadn't previously considered or covered in the literature review already.

Log Entry 02: 2023/07/13

Statement of project problem / research question (maximum 200 words)

"Can the manner in which deep learning has been shown to solve two-dimensional, forward electromagnetic scattering problems applied to the problem of predicting EM wave propagation over rural terrain, namely emulation, be expanded or improved upon?"

A complete reference for the paper

[2]–[4], please refer to the final bibliography.

Summary of paper (maximum 100 words)

This log entry deals with references concerning the domain of application for solver, namely biomedical. The references consulted were:

- Section 5.4 of "Case Study: Scattering from Red Blood Cells" of [2];
- Section 2.5.1 & Section 6 of [3];
- Table 1 of [4] titled "Microwave parameters of three breast tissue types at low (0.5 GHz), middle (2 GHz, 4 GHz, 6 GHz), and high (8 GHz) frequencies".

How is this paper relevant to solving your project problem or addressing your research question? (maximum 100 words)

These references were consulted when considering topic and parameter selection. The setting of carrier wave incident frequency, geometric scale and discretization outputs matter in sizing the data inputs for the deep learning model.

What are the strengths and weaknesses of the solutions/methods/technologies proposed in this paper? (maximum 100 words)

- [2] indicated that a 474 THz incident wave would be required, with a red blood cell having a length of roughly 7.7 micrometers. According to the text, such scales lead to matrix equations with dimensions of over 200,000. Using such large arrays for building ML models is not suitable with current resources and even generating a dataset with solved fields is far beyond what the remaining project time would allow.
- In [3], a model of the relative complex permittivity of human muscle tissue is described in Section 2.5.1. This is the basis for an illustration of Deep Regional Hyperthermia Treatment Planning in Section 6. The example is in the time domain and is too computationally intensive as it depends on three dimensions with multiple incident waves in the 90 MHz range. The main reason for setting aside this source is that, due to time constraints, the incident wave is fixed for all simulations. Creating a sophisticated look-up table for a set of relative permittivities and conductivities based on the carrier incident wave frequency would be wasteful.
- Leading on from [3], the student found Table 1 in [4]. It gives a description of the effective dielectric permittivity and conductivity for normal, benign tumor and cancer cell tissues in the GHz range. This allows for discretization in the scale of interest of 128 and 256 which are more easily accommodated in deep learning architectures.

Log Entry 02: 2023/MM/DD

Statement of project problem / research question (maximum 200 words)

"Can the manner in which deep learning has been shown to solve two-dimensional, forward electromagnetic scattering problems applied to the problem of predicting EM wave propagation over rural terrain, namely emulation, be expanded or improved upon?"

A complete reference for the paper

Summary of paper (maximum 100 words)

How is this paper relevant to solving your project problem or addressing your research question?
(maximum 100 words)

What are the strengths and weaknesses of the solutions/methods/technologies proposed in this paper? (maximum 100 words)

Complete Bibliography

- [1] A. P. M. Li, M. Li, and M. Salucci, *Applications of Deep Learning in Electromagnetics: Teaching Maxwell's Equations to Machines*. Institution of Engineering & Technology, 2023.
- [2] Ö. Ergül and L. Gurel, *The multilevel fast multipole algorithm (MLFMA) for solving large-scale computational electromagnetics problems*, 1st edition. in IEEE press series on electromagnetic wave theory. Chichester, West Sussex: Wiley-IEEE Press, 2014.
- [3] J. E. Houle and D. M. Sullivan, *Electromagnetic simulation using the FDTD method with Python*, Third edition. Hoboken, NJ: Wiley, 2020.
- [4] Y. Cheng and M. Fu, "Dielectric properties for non-invasive detection of normal, benign, and malignant breast tissues using microwave theories," *Thorac. Cancer*, vol. 9, no. 4, pp. 459–465, Apr. 2018, doi: 10.1111/1759-7714.12605.