

An Integral Equation Solver for 3D Electromagnetic Modeling based on Residual Guidance and Self-attention Mechanism

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Electromagnetic (EM) modeling, as a general tool for calculating and analyzing EM field distributions, is widely applied in fields such as radar detection and microwave device design. Essentially, popular EM modeling methods, such as the finite element method and the method of moments, all obtain the EM field distribution by discretizing the Maxwell equations under specific boundary conditions, converting them into matrix equations, and solving them. However, in practical applications, these matrix equations often contain a large number of unknowns, making the solution process highly time-consuming. This significantly limits the further development and application of EM modeling techniques.

To improve the efficiency of solving matrix equations in EM computations, a universal solver for EM modeling based on residual guidance and self-attention mechanisms (RGSA-Solver) is studied. This solver gradually updates the initial solution by stacking multiple residual guided update (RGUpdater) blocks, ultimately achieving an accurate solution to the matrix equation. Each RGUpdater block consists of a residual module and an update prediction module. In the residual module, the current residual is first calculated using the impedance matrix, excitation vector, and candidate solution. Inspired by the Krylov subspace method, a search direction vector is then introduced to assist in guiding the update of the solution. In the update prediction module, a self-attention mechanism is incorporated to predict the solution update based on the candidate solution residual, and search direction vector. Additionally, during the training phase, apart from the data residual, the discrete PDE residual is also introduced to ensure the accuracy of the proposed method when solving ill-conditioned matrix equations.

This paper extensively trains the proposed RGSA-Solver on a subset of the 3DEM Dataset, a 3D dataset for machine learning based EM computations, which includes thousands of CAD models, mesh data, and their surface current distributions. After 10 epochs of training, the mean square error (MSE) of the RGSA-Solver decreases to below 0.1 on both the training and testing sets, reaching a convergence state and exhibiting a very fast convergence speed. Subsequently, the trained RGSA-Solver is tested on the test set, various unseen CAD models, and many CAD models with multi-scale details, and the results are compared with those obtained by traditional iterative solver. Simulation results show that the proposed RGSA-Solver can solve EM scattering problems for various 3D objects, with solution accuracy comparable to that of iterative methods after sufficient iterations. However, the RGSA-Solver only requires 20 iterations, which is more than 100 times more efficient compared to iterative methods. Furthermore, the test results on unseen CAD models and CAD models with multi-scale details indicate that the RGSA-Solver exhibits excellent generalization ability and can adapt well to different incident angles, shapes, and numbers of unknowns.