A Tucker-Accelerated Volume Integral Equation Solver for 2D Scattering Problems

Arda Yalcinkaya[(1)], Xiaofan Jia[(1)], Yang Liu[(2)], Theng Huat Gan[(3)], and Abdulkadir C. Yucel[(1)]

(1) Nanyang Technological University, 639798, Singapore
(2) Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
(3) National University of Singapore, 117411, Singapore

The volume integral equation (VIE) solvers for 2D TM_z scattering problems have been indispensable for various applications, including geophysical exploration, non-destructive testing, and metasurface synthesis, just to name a few. These solvers provide the solutions of dense linear system equations, often accelerated by the fast Fourier transforms (FFTs). While FFT-accelerated VIE solvers offer highly favorable computational and memory requirements, they are not applicable to the analyses of multiscale structures discretized by non-uniform pixels (i.e., different-sized pixels). Furthermore, these solvers lose their efficiency while analyzing well-separated structures defined on a structured grid. To overcome these limitations, matrix decomposition-based compression schemes, such as singular value decomposition (SVD) (S. Kapur and D. E. Long, *IEEE Computational Science and Engineering*, 5(4), 60-67, 1998), adaptive cross approximation (K. Zhao, et.al., *IEEE Trans. Electromagn. Compat.*, 47(4), 763-773, 2005), and butterfly compression (H. Guo, et al., *IEEE Trans Antennas Propagat*., 65 (9), 4742-4750, 2017), are used to accelerate the VIE solvers. These schemes efficiently compress the low-rank blocks in the system matrices and perform the matrix-vector multiplications via compressed blocks during the iterative or direct solution of the linear system of equations. However, tensor decomposition techniques often provide superior compression and computational efficiency compared to these schemes. So far, tensor decomposition schemes, particularly tensor train-based ones, have been applied to the acceleration of various 2D static, quasi-static, and TM_z scattering analyses (Z.Chen, et al., *IEEE Trans. Microw. Theory Techn.*, 67(12), 4833-4847, 2019). On the other hand, the ones leveraging Tucker decomposition have been applied to the acceleration of various 3D static and quasi-static analyses. So far, no study proposes a Tucker decomposition-based acceleration scheme for the VIE solution of 2D TM_z scattering problems.

This study proposes a Tucker-accelerated VIE solver for 2D TM_z scattering analysis. The proposed solver hierarchically subdivides the computational domain into subdomains and compresses the low-rank blocks corresponding to well-separated subdomains. To do that, it converts 2D low-rank blocks into 4D arrays and efficiently compresses them via an interpolative decomposition (ID) Tucker scheme. The resulting Tucker-compressed tensors are then used to perform fast tensor-vector multiplications during the iterative solution of the linear system of equations. The proposed Tucker-accelerated VIE solver requires much less computational time and memory compared to matrix decomposition-accelerated VIE solvers. The preliminary results show that the proposed tensor-based solver yields 100x to 1000x memory reduction over the matrix-based solver leveraging ID-SVD with practical compression tolerances. In the talk, we will present comparative results, including compression ratios as well as memory and computational time requirements for various 2D TM_z scattering scenarios analyzed with the proposed Tucker-accelerated VIE solver and the reference ID-SVD accelerated VIE solver.