Tensor Decompositions for Memory Reduction in Integral Equation-Based Electromagnetic Simulators

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Today, the integral equation (IE)-based electromagnetic (EM) simulators are widely used for many purposes ranging from radar signature characterization, remote sensing studies, bioimaging analysis, wireless channel characterization, integrated circuit design, just name a few. Over the last three decades, IE-based EM simulators have been accelerated dramatically using techniques such as the fast multipole method (FMM), fast Fourier transform (FFT), and combination of both (FMM-FFT). These accelerated EM simulators allow analyzing many real-world structures. However, their applicability to large-scale and complex problems is often limited by their memory requirements, especially when executed on commodity desktop computers. To this end, several matrix decomposition methods leveraging singular value decompositions, multilevel matrix decompositions, cross approximations have been used to reduce the memory requirements of the large data structures in the accelerated IE-based EM simulators. However, no tensor decomposition methods except the ones in [1, 2], which presumably yield more memory reduction compared to matrix decompositions methods, have been used for this purpose. The tensor decomposition methods yield exceptional memory reduction and negligible computational overhead, primarily when used to compress the large tensors storing the Green's function, plane-wave expansion, and far-field samples on structured grids, arising in FFT-accelerated and FMM-FFT accelerated IE-based EM simulators.

This study compiles the *first time* our latest results on the application of tensor decomposition methodologies to the IE-based EM simulators for the analysis from DC to microwave frequencies. First, the Tucker decompositions are applied to reduce the memory requirement of our in-house VoxCap simulator, an FFT-accelerated electrostatic simulator. The results show that the proposed decomposition reduces the memory requirement of circulant tensors in VoxCap by 3-4 orders of magnitude while imposing negligible computational overhead. Next, the Tucker decompositions are used to lessen the memory requirement of VoxHenry, an FFT-accelerated magneto-quasi-static simulator; the performance obtained for VoxCap is also attained for VoxHenry. Last but not least, Tucker and tensor train decomposition-based methodologies are applied to reduce the memory requirement of an FMM-FFT-accelerated EM simulator for the analysis of electrically large structures at microwave frequencies. In particular, the translation operator and aggregation/disaggregation tensors of FMM-FFT-accelerated EM simulator are compressed after proper tensorization and implementation of fast compression/decompression schemes. The results show that more than %90 memory reduction achieved using the proposed decompositions. The FFT-accelerated and FMM-FFT-accelerated EM simulators enhanced by the tensor decompositions are executed on a commodity desktop computer for solving static problems involving hundreds of millions of unknowns and full-wave problems involving millions of unknows, respectively. In the talk, the results obtained for these large-scale problems will be presented after the memory savings achieved by and (negligible) computational overhead imposed by the proposed methodologies will be demonstrated for the canonical problems.

REFERENCES:

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