Efficient Parallel Algorithms for Electromagnetic Composite-Object Integral Equations

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Numerical simulation of electromagnetic phenomena has become an indispensable tool for engineers, and a critical link in the engineering design chain. Modern engineering challenges require electromagnetic analysis of complex systems comprising composite objects, i.e., those with both penetrable and impenetrable regions. Additionally, problems of engineering interest include electrically large structures, e.g., satellite communications antennas mounted on naval vehicles, with fine features. Among modern computational methods used to solve these problems, integral equations (IEs) are held in high regard for their accuracy due to their exact imposition of radiation boundary conditions. Fast methods for IEs, such as the fast multipole method (FMM) and the multilevel fast multipole algorithm (MLFMA), have been extensively studied, and reduce the cost of solutions from $\mathcal{O}(N^2)$ to $\mathcal{O}(N \log N)$, where N is the number of degrees of freedom in the problem. Even so, it is still infeasible to solve problems with very large N in a reasonable amount of time without further modifications to the solution algorithm to reduce the computational cost, limiting the utility of these methods for large, multiscale engineering problems.

Parallelization of these algorithms has been the thrust of much recent work. However, much of the work on development of efficient parallel algorithms has been devoted to analysis of perfectly conducting objects (L. Gurel & O. Ergul, Proc. IEEE, vol. 101, no. 2, pp. 332-341, 2013) with more limited work on composite objects. A different parallel implementation was proposed in (V. Melapudi et al., IEEE Trans. Antennas Propag., vol. 59, no. 7, pp. 2565-2577, 2011) which was shown to be highly scalable up to 512 processors. It is this algorithm that we will leverage in this work. To this end, we will augment domain partitioning by an intelligent pre-processing step to effect optimal distribution and alleviate communication costs. Our earlier incarnation of this work used a brute force partitioning of the space filling curve, the drawback of which is loss of scalability for high contrast inclusions. Furthermore, we will address development of efficient preconditioning strategies within the parallel framework.