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Fast High-order Nyström Methods for Electromagnetics

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The majority of electromagnetic devices important for radio-frequency and nanophotonic applications are notoriously challenging to design and analyze due to the lack of analytical solutions, necessitating fully vectorial solutions of Maxwell's equations. Unfortunately, these devices are often also difficult to solve numerically due to being electrically large (spanning many wavelengths in size) while simultaneously having subwavelength feature sizes. Time domain approaches, such as the Finite-Difference Time-Domain (FDTD) method, are often the only viable algorithms for simulating large electromagnetic problems, such as many-wavelength grating couplers or adiabatic tapers. This is because volumetric frequency-domain methods such as the Finite Element Method (FEM) or the Finite-Difference Frequency-Domain (FDFD) method result in prohibitively large linear systems which become intractable even for modestly sized problems. We have recently developed fast, high-order integral equation solvers based on the Nyström method, which can be used to efficiently and rapidly simulate large electromagnetic devices with finite features in the frequency domain, including nanophotonic devices with semi-infinite waveguides [1-4]. These solvers can accurately represent complex geometries with coarse discretizations by utilizing curvilinear quadratic patches and expanding the unknown densities on the surface in terms of Chebyshev polynomials. Instead of relying on the well-known, but expensive Locally Corrected Nyström (LCN) method for calculating the challenging singular and near-singular integrals, our Chebyshev-based solvers leverage a fast precomputation approach, which uses a rectangular change-of-variables whose Jacobian vanishes at and cancels the singularity. The Chebyshev-based method will be presented in detail, as well as some of our recent advancements, including a block sparse preconditioner for accelerating convergence of iterative methods and initial progress towards fast-direct H-matrix-based solvers. We will also demonstrate our recent extension of the method for solving scattering and propagation problems with uniaxially anisotropic media, resulting in the first ever boundary integral solver for uniaxially anisotropic materials with high-order accuracy.

1. J. Hu, E. Garza, and C. Sideris, "A Chebyshev-based high-order-accurate integral equation solver for Maxwell's equations," IEEE Transactions on Antennas and Propagation, 69(9), pp. 5790–5800, 2021.

2. E. Garza, J. Hu, and C. Sideris, "High-order Chebyshev-based Nyström Methods for Electromagnetics," IEEE International Applied Computational Electromagnetics Society Symposium (ACES) 2021.

3. E. Garza, C. Sideris, and O. P. Bruno, "A boundary integral method for 3D nonuniform dielectric waveguide problems via the windowed Green function," arXiv preprint arXiv:2110.11419, 2021.

4. C. Sideris, E. Garza, and O. P. Bruno, "Ultrafast simulation and optimization of nanophotonic devices with integral equation methods," ACS Photonics 6(12), pp. 3233-3240, 2019.