A Time-Domain Dual-Field Finite-Element Domain-Decomposition Boundary-Integral Method for Electromagnetic Scattering Analysis

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Numerical schemes, which are capable of analyzing transient scattering from an inhomogeneous object residing in an unbounded background medium, are indispensable in electromagnetics, optics, and photonics. Time-domain finite element method (TDFEM) is often used for this purpose. However, when the TDFEM is used to analyze an open-region scattering problem, the unbounded background medium must be truncated into a finite computation domain. This is often done by "wrapping" the computation domain with absorbing boundary conditions (ABCs) or perfectly matched layers (PMLs) (J. M. Jin, Theory and Computation of Electromagnetic Fields, New York: Wiley, 2010). The accuracy of the ABC decreases significantly for waves obliquely incident on the boundaries while the PML might introduce late time instabilities in the solution and its accuracy deteriorates at low frequencies (S. Abarbanel et al., J. Sci. Comput., 17, 405-422, 2002). Another approach for truncating an unbounded background medium is to "hybridize" the TDFEM with the time-domain boundary integral method (TDBIM) (D. Jiao et al., IEEE Trans. Antennas Propag., 60, 1969-1977, 2012). This hybrid approach is mathematically exact and the truncated boundary can be located very close to the scatterer surface (regardless of its shape). These ensure that an accurate solution is obtained on the smallest computation domain possible. The increased cost that stems from the computation of spatio-temporal convolutions required by the TDBIM can be accelerated using an FFT-based scheme (Ali E. Yilmaz et al., IEEE Trans. Antennas Propag., 55, 1382-1397, 2007) or the plane wave time domain (PWTD) method (B. Shanker et al., IEEE Trans. Antennas Propag., 53, 3704-3716, 2005).

In this work, a scheme, which hybridizes the dual-field finite-element domain-decomposition method (Zheng Lou et al., IEEE Trans. Antennas Propag., 54, 1850-1862, 2006) and the TDBIM for accurately and efficiently analyzing open-region transient scattering problems, is proposed. The computation domain is divided into smaller subdomains and in each subdomain the dual-field second-order vector wave equation is enforced/solved. Electric and magnetic fields are updated at staggered time steps so that the communication between subdomains can be realized by introducing equivalent surface currents on the interfaces between the subdomains. These equivalent currents are computed from previous time step's fields in the adjacent subdomains. The fields on the computation domain boundary are computed using the equivalent currents introduced on a Huygens' surface (enclosed inside the computation domain). These currents are computed from the known electric and magnetic fields. This approach is faster than the classical hybridization of the TDFEM and the TDBIM, since the small system matrices generated on each subdomain can easily be factorized and stored for directly solving the matrix system at every time step. Additionally, the efficiency of this technique can further be increased by using an element-level domain decomposition that results in a completely explicit time marching.

Numerical examples, which demonstrate the accuracy, efficiency, and applicability of the proposed method, will be presented.