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A fast algorithm based on partial basic solution vectors domain decomposition method for scattering analysis of electrically large cylinders

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Abstract

An efficient domain decomposition method (DDM) based on the partial basic solution vectors (PBSV) is presented for the electromagnetic scattering analysis of electrically large two-dimensional objects. The original computation domain is partitioned into nonoverlapping subdomains. The PBSV of each subdomain are evaluated independently. Then the field on the interfaces between subdomains can easily be obtained by an iterative vector summation procedure, and the final solution on each subdomain is solved independently and efficiently. To improve the algorithm further, two techniques, expanding the PBSV by roof-top basis functions and an under relaxed iteration method, are also studied. Compared with the traditional DDM, the proposed method can greatly reduce the computational complexity and the memory requirement; moreover, it can be implemented totally independently on both sequential and parallel computational platform, which is distinct from the others. The validity of this algorithm is verified by numerical examples.

Keywords: Domain decomposition method; Partial basic solution vectors; Electromagnetic scattering

1. Introduction

Because the electromagnetic scattering analysis of electrically large targets and geometrically complex structures has been playing an increasingly important role in electromagnetic field theory and practicable applications, the fast and rigorous methods for solving such problems are needed pressingly. Many numerical methods have been reported on this topic. As one of the most popular techniques, the finite element method (FEM) is well suited for problems involving inhomogeneous, arbitrary shaped objects. When FEM is used to solve unbounded problems, as is the case of electromagnetic scattering, the infinite space must be truncated using artificial boundary conditions to limit the size of the computational domain.

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Two major classes of boundary conditions have been developed and used extensively for FEM analysis of scattering problems [1]. The first class of boundary conditions is derived from the boundary integral equations [2,3]. These boundary conditions are precise and can be applied directly at the surface of the scatterer, which reduce the domain of calculation to a minimum. However, the coefficient matrix corresponding to such boundary conditions will be a partly full, partly sparse matrix, which is expensive to be stored and solved. The second class of boundary conditions is often called local boundary conditions, such as absorbing boundary conditions (ABCs) [4–6] and perfectly matched layers [7–9]. Since these boundary conditions relate the field at one point on the artificial boundary only to the field at its neighboring points, the corresponding coefficient matrix is always a sparse matrix, which can be stored and solved efficiently. However, the absorbing boundary must be placed enough far away from the surface of the scatterer to minimize the nonphysical reflected waves. Thus, for electrically large problems, this method will yield a huge coefficient matrix that may become prohibitive for today's computer platform.

To promote the computational efficiency, many studies have been reported. Between them, the domain decomposition method (DDM) is especially appealing [10–27,33]. Unlike other methods, the DDM does not deal with the whole computational domain directly, but divide it into several subdomains. Each subdomain is solved independently, and the contiguous subdomains are coupled through specific interface boundary conditions to guarantee the unique solution. Since the DDM can reduce the originally larger problem to several smaller problems, it greatly decreases the memory requirement; moreover, it is also well suited for numerical implementation on parallel computers. An efficient domain decomposition technique for the method of moments (MOM) was reported in [10]. A parallel technique for two-dimensional (2-D) FEM analysis was introduced in [11,12]. This algorithm employed the tangential field continuity conditions to exchange information between the subdomains. In mechanical engineering community, a finite element tearing and interconnecting method (FETI) was presented by Farhat et al. in [13] to focus on the parallel computing, which was based on the hybrid variational principle with the help of Lagrange multipliers. Although the FETI have been extended to electromagnetics problems [15,16], it might cause "floating subdomains". To avoid the shortcoming, a modified FETI algorithm FETI-H was developed for Helmholtz problems in [14] by introducing the interface matrix. Recently, A fast DP-FETI algorithm was presented in [17–21,33], which was highly efficient for problems with geometric repetitions, such as photonic and electromagnetic band gap structures. In [22], Després presented an iterative algorithm and a Robin type transmission condition, i.e., the Després DDM, for the 2-D Helmholtz equation. Later in [23], Després extended his method to Maxwell's equations. Stupfel used the Després method to analyze electromagnetic scattering problems by an "onion-like" partition scheme of the computational domain [24,25]. Hong et al. introduced the Després DDM to finite difference frequency domain (FDFD) method and presented a more efficient partition scheme [26]. In [27], a mixed algorithm of the Després DDM and the measured equation of invariance (MEI) [28] was developed for the 2-D electromagnetic scattering problems.

The major drawback of the conventional DDM is that one has to repeatedly solve the matrix equation on each subdomain and enforce the field continuity by using transmission conditions or Lagrange multipliers until the desired accuracy is achieved. Hence, the efficiency is heavily dependent on both the computational complexity of each subdomain and the iterative method for communication between subdomains. As mentioned above, for electrically large problems, the DDM can greatly reduce the memory requirement. However, in practice, it can not decrease the CPU time significantly [27], especially on a common PC. For example, suppose the original computation domain consists of N unknowns and is equally decomposed into m subdomains; then the CPU time spent by the DDM can be estimated as $n/m \cdot \mathrm{O}(N)$, where n is the total number of iterations to arrive at the desired accuracy. Unfortunately, n is often many times larger than m, and thus the computing time of the DDM might be considerably longer than that of the conventional methods.

In this paper, we present a novel DDM algorithm based on our previous work [27] for the analysis of electromagnetic scattering problems of 2-D electrically large objects by introducing the partial basic solution vectors (PBSV) of the matrix equations, and we denote it by "partial basic solution vectors based domain decomposition method (PBSV-DDM)", which can be viewed as a combination of the Després DDM and the method of moments. This paper is organized as follows. In Section 2, the Despré DDM is reviewed briefly. The basic theory of PBSV-DDM are described in Section 3.1. To improve the efficiency further, two techniques, expanding the PBSV by roof-top basis functions and an under relaxed iteration method, are studied