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HYBRID ALGORITHM BASED PARALLEL SOLUTION TO ELECTROMAGNETIC SCATTERING FOR ARBITRARY SHAPED CAVITIES

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Abstract. The Radar Cross Section (RCS) prediction for cavities is significant to measure a target's radar detection ability. For electrically large, deep, arbitrary shaped cavities, this paper presents a hybrid algorithm based parallel solution using Message Passing Interface on distributed memory computers. The meaning of 'Hybrid' here is threefold. First, the RCS for cavities is modeled and calculated with a hybrid algorithm of IPO (Iterative Physical Optics), FMM (Fast Multipole Method) and Generalized Reciprocit Integral (GRI) combined by a cascading segmentation technique. Second, a hybrid approach is applied to the two phases of parallelization. On phase of geometrical preprocessing, all parallel processes assume a whole workload to construct the cavity geometry independently. On the other phase of electromagnetic computing, the workload is distributed by domain decomposition. Third, the decomposition scheme is hybrid as facets are decomposed to compute near-field interation while angle samples are used to distribute far-field interaction. The superposition of electromagnetic measures and permutability of math vector operations are fully exploited to do partial computation in order to minimize the communication overhead. The hybrid parallel solution can achieve very good tradeoff between memory and time. It yields a good load balance while still keeping the parallel code pretty concise. Numerical results show near-linear scalability and over 90% parallel efficiency.

Key words. Radar Cross Section, Cavity, Parallel, Iterative Physical Optics, Fast Multipole Method, Hybrid algorithm.

1. Introduction

As a measure of the detection ability of a target in radar systems, the Radar Cross Section (RCS) has been an important topic in electromagnetic research. The RCS prediction for cavities is particularly important for its dominance in the target's entire RCS. For example, the engine inlet and exhaust ducts may contribute very significantly to the RCS of modem jet aircraft. Thanks to its significant industrial and military applications, the cavity problem has attracted much attention. A variety of methods, such as Waveguide Model Analysis, IPO (Iterative Physical Optics) and FMM (Fast Multipole Method), have been proposed to solve the arbitrary shaped cavity problems [1][2][3][4]. For arbitrary shaped and electrically large cavities, a hybrid algorithm connecting IPO, FMM and GRI (Generally Reciprocal Integral) with Cascading Segmentation scheme was recognized to be an efficient way to solve scattering problems. A serial implementation of the hybrid algorithm was presented by our partners [5]. Tested experiments demonstrated its accuracy and efficiency in comparison with model reference solutions.

However, when the number of unknowns becomes very large, say tens or hundreds of thousands, it is beyond the capability of the serial version with respect

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to memory requirement or time requirement. Although FMM and its recursive variant, the multilevel fast multipole algorithm (MLFMA), have been successfully implemented on various parallel computers and their good performance has been well reported [6][7][8][9][14], it is not so in the case of the hybrid algorithm for cavities. Indeed, there have been very few attempts at parallel implementation for analysis of RCS of cavities. In [13] a parallelization approach of the finite element-boundary integral-multilevel fast multipole algorithm (FE-BI-MLFMA) is presented for scattering by large and deep coated cavities loaded with obstacles. And [11][12] introduces our preliminary work on parallelizing IPO and FMM for straight cavities. This paper will extend the range of problems that can be solved by the previous serial implementation and discuss the parallelization based on the hybrid algorithm to compute RCS of any electrically large, deep and arbitrarily shaped cavities using the Message Passing Interface (MPI) [15].

The rest of this paper is organized as follows. In Section 2 the primary computation of the serial hybrid algorithm is briefly reviewed, which provides a basis for parallelization. In Section 3, the parallel methodology is discussed, followed by a detailed analysis of communication, computation and storage overhead. Numerical results are presented in Section 4 to demonstrate the effectiveness of the parallel solution. Finally comes the summary.

2. Hybrid algorithm for RCS of cavities

To analyze the highly complex high-frequency scattering problem from electrically large open cavities, IPO approach [1] was proposed by F.O.Basteiro etc. in 1995 which iteratively applies the high-frequency asymptotic principles of physical optics to account for multiple reflections inside the cavity. The IPO algorithm has been shown as a much efficient and high accurate although numerically intensive approach in analyzing electro-magnetic scattering by very large and complex cavities. The FMM, an approximation technique which reduces the complexity of matrix vector product of M order from $O(M^2)$ to $O(M^{1.5})$, was proposed by Rokhlin at the University of Yale in the end of 80s. It was applied by C.C. Lu, etc. to accelerate the RCS computing of large and complex objects [7]. And FMM could also be employed to speed up the iterative process of IPO [5]. The Segmented approach for analyzing the electromagnetic scattering of arbitrary shaped cavities [3] was also proposed by F. O. Basteiro etc in 1998. In this approach, the cavity is divided into two different parts: the front section (typically smooth) and the complex termination. The front section is subdivided into several sections, see Figure 1 for an illustration,where $W^+ = \begin{bmatrix} E^+ \\ H^+ \end{bmatrix}$, $W^- = \begin{bmatrix} E^- \\ H^- \end{bmatrix}$ are the tangential components of the incident and reflective electromagnetic field respectively. Each section is analyzed independently from the rest of the cavity. Genera-lized Reciprocity Integral (GRI), proposed by Pathak and Burkholder in 1993 [4] for cavity with complex termination, is applied to the segmented approach to avoid retracing back, which is quite time-consuming.

For the RCS problem of arbitrary shaped and electrically large cavities with complex termination, a hybrid algorithm combined IPO, FMM and GRI with Cascading Segmentation technique is more desirable for accuracy and efficiency than any single method of them [5] . The computation process for the hybrid algorithm is briefly described as follows.

Step1—Incident Field on Wall (IFW): For section k, the incident magnetic field on the inner wall induced by electromagnetic fields (or incident wave when