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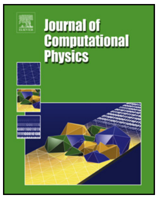

Combination of ray-tracing and the method of moments for electromagnetic radiation analysis using reduced meshes

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ABSTRACT

This work presents a technique that allows a very noticeable relaxation of the computational requirements for full-wave electromagnetic simulations based on the Method of Moments. A ray-tracing analysis of the geometry is performed in order to extract the critical points with significant contributions. These points are then used to generate a reduced mesh, considering the regions of the geometry that surround each critical point and taking into account the electrical path followed from the source. The electromagnetic analysis of the reduced mesh produces very accurate results, requiring a fraction of the resources that the conventional analysis would utilize.

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1. Introduction

Different factors have contributed during the last decade to a drastic increase of the application scope of electromagnetic simulation methods. It is worth to mention, among them, the sustained increase of the computational power of cluster systems, workstations and personal computers, or the rise of different parallelization paradigms from which numerical simulation algorithms are greatly benefited. It must be noted, however, that even more important has been the development of highly efficient algorithms that reduce the computational burden of legacy approaches, while maintaining a high degree of accuracy.

Regarding the application of Boundary Element Methods (BEM), many of the modern approaches are based on variations of the Method of Moments (MoM) [1]. The legacy MoM approach results computationally prohibitive even for moderately small problems and considering modern systems, because it requires a discretization of the geometry with a typical sampling rate of 10 subdomains per wavelength, which generates a dense system of equations described by a coupling matrix whose size precludes the simulation of many realistic cases. Modern approaches, therefore, avoid the computation and storage of the full MoM matrix and store instead the near field coupling matrix, which only contains the coefficients that represent the coupling terms between subdomains that are electrically close to each other (involving typically a distance of around $\lambda/4$). This matrix is sparse, much smaller than the original one and generally includes the coefficients that are very close to the diagonal of the full MoM matrix. The rest of the coefficients are not directly computed, but are taken into account in the iterative system solution process. One of the most popular techniques to account for the contributions of the far field coupling terms is the Multilevel Fast Multipole Algorithm (MLFMA) [2], that, after partitioning the geometry in terms of regions, computes the aggregation of all the currents to the center of their corresponding region, and then applies

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a translation of those multipole expansions to the region of the passive subdomain function, allowing to consider multiple contributions at the same time. There are methods such as the Adaptive Cross Approximation [3] that, in turn, provide matrix compression by taking advantage of the fact that the submatrices of the MoM matrix that represent the coupling between distant parts of the geometry are rank-deficient and can be approximated by the product of two smaller matrices. Other approaches use Macro Basis Functions [4] defined over extended domains in order to decrease the number of basis functions of the problem and, consequently, the size of the linear system to be stored and solved.

Even with these considerations there are problems that still do not render themselves suitable to be analyzed using efficient full-wave methods due to their electric size or to other aspects, as for example the necessity of simulating a large number of scenarios in an optimization process. In these cases the geometry may fall within the scope of some high-frequency asymptotic methods [5] such as Physical Optics [6,7], which eliminates the coupling dependence between subdomains and computes the currents by considering only the impinging field on the surface due to the external excitations. Several efficient approaches have been developed to compute the fast integration of the PO currents in order to obtain the scattered fields, such as the case of analytical integration of surface current distributions with linear [8] or quadratic phase variations [9]. Analytical integrals based on polynomial approximations of the amplitude and phase of the currents are used in [10]. Fast approaches for the computation of the PO integral based on the path deformation technique for 2D and 3D scenarios have been presented in [11,12]. The Geometric Theory of Diffraction (GTD) [13] bypasses the definition of surface currents and performs the analysis based only of the paths followed by rays associated to different electromagnetic effects. This makes the computational requirements of GTD independent of the electrical size of the scenario under analysis and, instead, becomes sensitive to the complexity of the geometry, and more specifically to the number of surfaces used to model the geometry and to the type of these surfaces. There are works that hybridize different asymptotic methods [14], or even asymptotic and rigorous methods, defining different types of zones on the scenario [15,16]. The ray-tracing process [17] involved in the GTD approach can take advantage of algorithms such as the Angular Z-Buffer (AZB) [18], that classifies efficiently the surfaces of scenario and the type and order of the effects into angular regions, or the Space Volumetric Partitioning (SVP) [18–20], which instead uses a partition of the geometry in terms of cubic volumes in order to discard surfaces for collision tests.

The technique presented in the following sections of this document is based on the generation of a reduced scenario using the information provided by a ray-tracing analysis. The new mesh is then analyzed using the MoM-MLFMA approach. The size of the problem can be noticeably reduced, easing the computational requirements of the simulation while maintaining a high degree of accuracy. The generation of the new scenario takes into account the information of the points of the ray-tracing located on the object under analysis and their surroundings. The reduced scenario excludes the parts of the original mesh with a low contribution to the final result. For this purpose different types of effects are taken into account as well as their combinations using multiple order interactions. The ray-tracing process makes use of the Angular Z-Buffer algorithm as well as the Space Volumetric Partitioning to accelerate the computation of the rays associated to all the effects involved in the simulation.

Section 2 of this document presents the details of the algorithm proposed for the identification of the critical points using the ray-tracing information, as well as the critical regions corresponding to the critical points. Section 3 presents some cases used to test the performance of this technique, in terms of its accuracy and computational efficiency. The conclusions of the presented technique and results are discussed in Section 4.

2. Description of the approach

In order to describe in detail the operation of the technique proposed in this work, a geometry and an arbitrary number of external source excitations are considered, as well as a number of observation points or directions where the radiated fields are to be computed. The geometry can be described by a set of surfaces and, after a meshing process, a mesh that contains a number of geometrical elements or subdomains is generated. Let in this case denote the original mesh as M, and consider that the total number of subdomains in M is N_s as follows:

$$M = \bigcup_{i=1}^{N_s} S_i \tag{1}$$

where S_i stands for the i-th subdomain contained in the original mesh.

The strategy described in this document relies on the replacement of the original mesh by an alternative one that is noticeably smaller than the original and, for the source and observation points or directions of the problem under analysis, can be analyzed using a conventional MoM-based approach in order to return accurate results. The reduced size of this new scenario offers lower simulation times and memory requirements. Fig. 1 illustrates a simple outline of the steps required to apply this approach and which will be described in the rest of the document.

Special emphasis should be given to the fact that, following this procedure, the currents and scattered fields will be calculated using the MoM and not a high-frequency method, which will include the contributions of all the effects predicted by the ray-tracing analysis.

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