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A finite element method for the analysis of radiation and scattering of electromagnetic waves on complex environments

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Abstract

A hybrid finite element method (FEM) and high frequency technique (HFT) for the efficient analysis of the radiation and scattering of electromagnetic waves on complex environments is presented. It makes use of FEM for the regions with small and complex features and a HFT for the analysis of the electrically large objects of the structure, taking into account mutual interactions between the FEM domains and the objects analyzed with HF techniques. Results of the analysis of two-dimensional scattering and radiation problems using Physical Optics as the high frequency technique are given showing the main features of the method.

Keywords: Electromagnetics; Finite element method; Hybrid method; Physical optics; Scattering and radiation

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1. Introduction

The analysis of the radiation and scattering of electromagnetic waves on complex environments is an important issue that finds application in many electromagnetic engineering areas, e.g., the design of antennas mounted on complex platforms (as those on board of ships and aircrafts) and/or surrounded by complex objects, and in the prediction of the radar cross section of large objects having small and/or complex features.

The efficient numerical modeling of such phenomena is a challenging problem, requiring, in general, a combination of different methods. This is due to the presence in the same domain of the problem of inhomogeneous (possibly anisotropic) media, arbitrarily shaped structures, and electrically large (metallic and/or dielectric) objects.

In this paper, a hybrid method combining the finite element method (FEM) and high frequency (HF) techniques is presented. It makes use of FEM for the regions with small and complex features and a HF technique for the analysis of the electrically large features of the structure. This hybrid method also makes use of the radiation boundary condition of the integral equation (IE) representation of the field for the truncation of the FEM domain. However, it does not use the IE representation in the conventional way but in an iterative fashion, as it is explained below. Thus, it combines methods based on differential equation (DE), integral equation (IE), and HF methods. It is worth noting that it does combine them on a full coupled basis, i.e., by taking into account mutual interactions between the FEM domains and the objects analyzed with HF techniques.

With respect to the FEM analysis of open region problems, it may be done in several ways (a review from a mathematical point of view may be found in [1]). Specifically, it is worth noting the use of local absorbing boundary conditions [2–7], more general Dirichlet to Neumann (DtN) maps [8–10], infinite elements [11–13], boundary element techniques [14–17] and perfectly matched layers [18,19]. The hybrid approach presented here is based on an improved version of an iterative method for the FEM analysis of 2D and 3D (static and full wave) open-region problems previously proposed by the authors [20–24]. At each iteration, this method reduces the FEM analysis of an open-region problem to the conventional FEM analysis of a closed-domain problem. A local type boundary condition is used at the FEM mesh truncation boundary (called external boundary) which is updated for the next cycle of the iteration procedure by the use of the Green's function of the exterior problem.

Thus, an accurate representation of the radiation boundary condition is obtained (allowing the external boundary to be placed close to the sources) while the sparsity of the FEM matrices is retained. The iterative nature of this method provides several advantages, among them, the possibility of reuse FEM computer codes for non-open region problems and an easy hybridization with other techniques by means of interfacing with them in the iterative loop. Specifically, the coupling with the HF technique is achieved by modifying the Green's function that is used to update the external FEM boundary condition.

The organization of the rest of this paper is as follows. The hybrid method is described in Section 2. The method as presented is suitable to be applied to a wide variety of open-region problems and with different HF techniques. Examples of its application to the analysis of 2D scattering and radiation problems, using physical optics (PO) as the HF method, are shown in Section 3. Results illustrate the main features of the method and its validity for the type of problems mentioned above. Finally, several conclusions are presented in Section 4.

2. Hybrid method

Consider the problem illustrated in Fig. 1. It consists of a region (bounded by an arbitrarily shaped auxiliary boundary S') with small features and a complex configuration where there are several materials