An Automatic Mesh Refinement Method Based on Phase Extracted Basis Functions for Electromagnetic Scattering Analysis of Electrically Extra-Large Objects

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Electromagnetic (EM) scattering problems are commonly solved by numerical methods such as the finite element method (FEM) and the method of moments (MoM). In a numerical simulation, the solution domain needs to be discretized into small mesh elements. The quality of the mesh is critical for the solution accuracy. While a denser mesh with smaller elements can result in a better numerical accuracy, it also leads to higher computational and storage costs, making it expensive to solve scattering problems from electrically large objects. To reduce such costs, higher order basis functions (HOBFs) [1] have been developed and applied in EM analysis. By expanding the amplitude of the induced surface currents with the HOBFs, larger mesh elements can be used, which reduce effectively the total number of unknowns required in solving an EM problem. For objects with smooth and convex surfaces, it has been shown in [2] that describing the phase variation of the induced surface currents can reduce the total number of unknowns even more effectively. By incorporating a traveling wave phase factor into the traditionally used low-order curvilinear Rao-Wilton-Glisson (RWG) basis functions, the resulting phase extracted basis functions (PEBFs) can be defined on mesh elements as large as half a wavelength. The combination of the PEBFs and HOBFs can reduce the number of unknowns by two orders of magnitude, which improved the simulation efficiency significantly while maintaining a good numerical accuracy [3].

While the use of PEBFs in smooth and convex objects demonstrated their modeling capability, when it comes to the modeling of objects with geometrical discontinuities, such as edges, corners, and tips, and those with strong physical mutual couplings, such as reflectors and cavities, the modeling efficacy of the PEBFs deteriorates. Although the combination of PEBFs and HOBFs can be used to model these objects, the HOBFs are defined on all mesh elements, even for those in smooth and convex regions where PEBFs alone are sufficient. In this work, a nonuniform mesh is employed, where a finer mesh is used to describe geometrical discontinuities and physical couplings such that standing wave distributions can be properly modeled, and a coarser mesh is used to describe smooth and convex areas of the scatterer such that traveling wave distributions can be properly modeled. To identify areas that need finer mesh elements, an automatic mesh refinement (AMR) method is proposed by exploring the unique traveling-wave-describing nature of the PEBFs. In this method, an initial coarse mesh is first employed, on which the PEBFs are defined and utilized to obtain a fast but "rough" solution of the scattering problem. Based on such a rough solution, the AMR method is applied to automatically distinguish areas that need a finer mesh from those that do not, which generates a nonuniform and nonconformal mesh from the initial coarse mesh. In order for the MoM to process the nonconformal mesh, the discontinuous Galerkin integral equation (DGIE) method [4] is employed with the PEBFs to solve the scattering problem. The DGIE method permits the PEBFs to be discontinuous across a nonconformal interface of two mesh elements and therefore, is highly suitable to be employed in the MoM simulation of electrically extra-large problems with the PEBFs and the AMR.

In the presentation, the proposed AMR method will be described in detail, the performance of the PEBFs in solving convex and concave problems will be demonstrated. The solution accuracy and efficiency of the proposed method will be compared with the traditional methods that use uniform meshes. Demonstration and application examples of the proposed methods in solving electrically extra-large scattering problems from real-world objects will be given.

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