A Scalable Nested Preconditioner for Improving the AIM-Accelerated Analysis of Antennas Near the Human Body

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The analysis of antennas operating near the human body in the UHF band (0.3-3 GHz) is a computationally challenging task because (i) the problem exhibits mixed-frequency characteristics, i.e., the field variations are dictated not just by geometrical features but by wavelengths/skin depths as well, (ii) complex antenna structures including thin good conductors must be modeled accurately, and (iii) modeling the inhomogeneous human body requires a large number of degrees of freedom. A promising method for this analysis is the adaptive integral method (AIM)-accelerated iterative method-of-moments solution of the frequency-domain surface-volume electric-field integral equation (SV-EFIE). Unfortunately, the formulation results in a poorly conditioned impedance matrix that causes the iterative solution to converge slowly and increases the computational costs of the method. Recently, a localized preconditioning technique was presented for improving the convergence (F. Wei and A. E. Yılmaz, Proc. of ICEAA, 869-872, Sep. 2012). The proposed block-diagonal preconditioner consisted of two blocks: The smaller block contained the inverse of the square matrix corresponding to the surface-to-surface portion of the impedance matrix; the larger block contained the inverse of the diagonal entries of the volume-to-volume portion. The preconditioned method was used to analyze radiation from a half-wave dipole in the presence of a human body model with $\sim 10^7$ degrees of freedom. The results showed significantly reduced number of iterations that remained constant as the resolution of the body model was increased. While it is effective if the antennas can be modeled with few degrees of freedom, this relatively simple preconditioning technique quickly becomes unfeasible for complex antennas, because it requires the inversion of a dense matrix.

In this article, a nested preconditioning technique is proposed by building on the truncated multigrid (tMG) preconditioner proposed in (F. Wei and A. E. Yılmaz, Proc. URNC/URSI Rad. Sci. Meet., July 2012) and the aforementioned localized preconditioner. The method is implemented using a flexible inner-outer Krylov subspace solver (Y. Saad, SIAM J. Sci. Comput., 14, 461-469, 1993). The outer iterative solver approximates the impedance-matrix vector product using AIM; it is implicitly preconditioned by the inner iterative solver that approximates the impedance-matrix vector product using an inaccurate but cheap tMG algorithm (based on coarsening the AIM grid). The inner iterative solver itself is explicitly preconditioned by using a block-diagonal matrix that consists of two blocks: The smaller and larger blocks contain a sparse approximate inverse (SAI) of the surface-to-surface portion and the inverse of the diagonal entries of the volume-to-volume portion of the impedance matrix, respectively. To implement SAI, the sparsity pattern of the approximate inverse is set to that of the AIM near-zone matrix. These choices allow both the explicit and implicit preconditioners to be parallelized using the load-balancing schemes developed for AIM. At the conference, the effectiveness and scalability of the proposed preconditioner will be demonstrated for various antennas, including patch antennas, near anatomically realistic high-resolution human body models.