MLFMA Based Characteristic Mode Analysis of Inhomogeneous Media

Di Wu, Dongliang Zhang, and Qi Wu*
(1) Beihang University, Beijing, China; e-mail: diwu07@buaa.edu.cn; qwu@buaa.edu.cn

Theory of characteristic mode (TCM) has become more popular among the antenna society in recent years since it can provide possible physical insights. With excitation-independent eigenmodes obtained by TCM, designers can analyze basic electromagnetic properties of any radiator, such as the resonant frequency, radiation pattern, and quality factor. Although many engineers have used TCM for assistance during the design stage, most of the structures have been simplified to perfect electric conductor (PEC). Moreover, large structures composed of complex materials are seldomly discussed due to the absence of related TCM technique [1][2].

Recently, TCM of inhomogeneous medias has been reported in [3]. Half-SWG basis function is utilized to expand the volume current density at the interface of two materials, and the resulting method of moment (MoM) matrix is numerically symmetric. Characteristic currents of both the lossless and lossy media maintain good orthogonality. However, MoM combined with volume equivalence results in more unknows than that with surface equivalence, and the computational burden becomes unaffordable for complex medias. In order to alleviate this issue, multilevel fast multipole algorithm (MLFMA) is employed to accelerate the matrix vector multiplication (MVM) [4]. The eigenvalue equation for inhomogeneous structure is transformed into the following format to implement MLFMA,

$$[Z_M + Z_V]^{-1}[R_V][I_V^n] = \alpha_n [I_V^n],\ \alpha_n = 1/(1 + j\lambda_n) \tag{1}$$

The above equation can be solved with the implicitly restarted Arnoldi method (IRAM). The MVM of $[R_V]\cdot[I_V^n]$ can be factorized into the far-field interaction (FFI) and the near-field interaction (NFI), where the FFI can be realized by the multiplication of disaggregate, translation, and aggregate matrices as

$$u = [R_V]\cdot[I_V^n] = [R_V]_{NFI}\cdot[I_V^n] + [D_V]\cdot[T_V]\cdot[A_V]\cdot[I_V^n] \tag{2}$$

As for the calculation of $[Z_M + Z_V]^{-1}\cdot u$, the generalized minimal residual (GMRES) iterative algorithm can be adopted, where the relative MVM is accelerated with MLFMA.

Eigenvalues of a coated sphere is calculated to verify the proposed method. The setting of the material parameters is the same as the one in [3]. The first 6 modes are compared, and the results obtained with MLFMA-accelerated MVM are almost identical to those with MoM-based MVM. The consumed time and peak memory of the IRAM iteration process are exhibited in Table 1, and it is shown that both quantities are reduced by over 75%.

Table 1. Comparison of computation resources between different methods.

	MoM-based	MLFMA-accelerated
Time Consumption (s)	579	139
Peak Memory (Gb)	10	1.89

References

[1] Q.I. Dai, J. Wu, H. Gan, et al., “Large-scale characteristic mode analysis with fast multipole algorithms,” IEEE Transactions on Antennas and Propagation, 61 (7), pp. 2608–2616, Jul. 2016.

[2] Q. Wu, “Characteristic mode formulations of composite PEC and lossy dielectric objects,” IEEE Antennas and Wireless Propagation Letters, 21(8), pp. 1557–1561, Aug. 2022.

[3] D. Wu, Q. Wu “Characteristic Mode Analysis for Inhomogeneous Media,” IEEE Conference on Antenna Measurements and Applications (CAMA), December 2022.

[4] Cai-Cheng Lu, "A fast algorithm based on volume integral equation for analysis of arbitrarily shaped dielectric radomes," in IEEE Transactions on Antennas and Propagation, vol. 51, no. 3, pp. 606-612, March 2003.