Multiple scattering of closely packed nonspherical objects using vector spheroidal waves and vector addition theorem

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Multiple scattering by spherical particles has been extensively studied and well established, where vector spherical waves are used [1,2]. However, many real-life objects are nonspherical such as dust, ice particles, and vegetation elements (e.g., branches, leaves and trunks). In this paper, we develop a hybrid method to calculate the multiple scattering of closely packed arbitrary-shaped objects, based on the rigorous solutions of Maxwell equations in the form of Foldy–Lax multiple scattering equations (FL). This method is a hybrid of the off-the-shelf techniques (e.g., HFSS) and newly developed techniques. The newly developed techniques are the three key steps of the hybrid method: (1) extracting the T matrix of each single object using vector spheroidal waves, (2) vector spheroidal wave transformations, and (3) solving FL for all the objects, which are detailed below.

The T matrix relates the incident fields to the scattered fields for an arbitrarily-shaped scatterer [1,3]. Previously, vector spherical wave expansions were used for T matrix [1, 3]. However, when the objects are closely packed, it is impractical to enclose each object by a spherical surface without overlap. In general, spheroidal surfaces are more compact to enclose closely packed objects such as clustered vegetation elements. Thus, vector spheroidal wave expansions are used here, which are more complex than the spherical waves. To extract the T matrix for an arbitrary-shaped object, we use the off-the-shelf technique HFSS which is a 3D full wave electromagnetic field simulation tool. HFSS allows the simulations of complicated structures that exist in a single object. To extract the T matrix of the single object from HFSS, we first define a spheroidal surface (∂S) which encloses the object. Then, we excite the object using incident plane waves at different incident angles and polarizations in HFSS. By numerical integration of the scattered fields from HFSS with the vector spheroidal waves over ∂S, the vector spheroidal wave expansion coefficients of the scattered waves are obtained. Since the expansion coefficients of the incident plane waves are known [3,4], the T matrix is extracted. It is noted that the T matrix extraction method works for arbitrary-shaped objects, including those required a spheroidal surface with a large aspect ratio (e.g., branches with leaves). The second step is vector spheroidal wave transformations. To find the scattered fields from object *a* to object *b*, the outgoing spheroidal waves centered at object *a* need to be transformed to incoming spheroidal waves centered at object *b*, which is also called translation addition theorem. We develop robust numerical methods to perform wave transformations for vector spheroidal waves. Finally, the extracted T matrices for the single objects are substituted to FL, and the FL is solved utilizing the numerical wave transformations. In solving FL, the coherent wave interactions among the objects are considered and the multiple scattering of all the objects is calculated. The hybrid method using vector spheroidal waves has applications such as full wave simulations of trees which can be decomposed into single nonspherical objects (e.g., trunks and branches with leaves).

References

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