3D Modeling of Complex Structures with the BCGS-FFT-DDM

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The Stabilized-BiConjugate Gradient Method with the Fast Fourier Transform (BCGS-FFT) calculating the matrix-vector multiplication has long been used as the fast solver in the volume integral equation (VIE) method to model the 3D scattering problem. However, due to the Toeplitz property requirement of the coefficient matrix, the current applications of BCGS-FFT are generally limited to the objects located in homogeneous background or in the same layer of the layer-medium background. For those problems with objects locating in different layers, FFT cannot directly be applied, which results in low efficiency and huge memory requirement for large scale problem, the bottleneck encountered in conventional VIE. Even for those problems with objects locating in the same layer or with complex structures, the current solver would require large computational domain to include all the objects, which also results in low efficiency.

To overcome these problems, the BCGS-FFT combined with domain decomposition method (DDM) is proposed in this work. DDM has received admirable reputation for its application in the finite element method (FEM) and the surface integral equation (SIE) method to solve the multiscale problems. Some of its application has also been proposed in the VIE, however, its combination with the BCGS-FFT has rarely been involved.

With the BCGS-FFT-DDM, the objects or different parts of an object are first treated separately, forming the self-coefficient matrices satisfying the Toeplitz property, and the couplings among the different objects/parts are then taken into account, where the coupling matrices can be built to satisfy the 2D Toeplitz property if the objects/parts have the same mesh distribution on the xy-plane. In this case, 3D FFT and 2D FFT can respectively be applied to accelerate the self-coefficient and coupling matrices-vectors multiplication.

In the previous studies of the VIE-DDM, the so called inner iterations and outer iterations are involved to treat the self-part and coupling part, and the convergence condition need to be well considered. However, in the BCGS-FFT-DDM, the linear system is formed as one including both the self-part and the coupling part, and the solver would generally be convergent for problems with considerable contrasts.