A mixed order BCGS-FFT based fast 3D inverse electromagnetic scatterings for anisotropic objects

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The purpose of the electromagnetic (EM) inverse scattering problems is to estimate EM properties of unknown objects within area of interest with known scattered EM fields. Three dimensional inverse scattering problems can be conveniently modeled by volume equivalence theorem. The volume equivalence theorem describes the forward scattering problems by volume integral equations. Estimating unknown EM properties of objects from these volume integral equations is a nonlinear problem. The born iterative method (BIM) and the distorted born iterative method (DBIM) are proposed to efficiently solve the nonlinear problems (Y.M. Wang and W.C. Chew Int. Jour. Imaging Sys. Tech. 1, 100-108, 1989). The BIM is more stable with noisy data and the DBIM converges faster.

Direct solver for the forward scattering problem determines the efficiency of the BIM and the DBIM. In both nonlinear integral equations solvers, a forward scattering problem has to be solved in each iteration. A BCGS-FFT based integral equations solver is widely used to solve the forward scattering problem. The conventional BCGS-FFT solver can only handle objects with relatively small electric size or small contrasts. The BCGS-FFT method with higher order basis functions may be used towards larger size and larger contrasts objects. However it may not be feasible for imaging objects with complex materials.

In applications such as biomedical imaging or subsurface imaging, the EM properties of objects may be complicated. In biomedical imaging for example, anonymous tissue among healthy tissue may have strong scattering when injected with malignant cell targeted nano-materials. Furthermore new contrast enhanced imaging technique in subsurface imaging applications involve solving for anisotropic magnetodielectric objects due to the injection of contrast agents. To tackle the scattering of these complicated objects, a mixed order BCGS-FFT method is employed.The mixed order BCGS-FFT method take advantage of mixed type and mixed order basis functions for higher accuracy and better compatibility for complex materials. In the mixed order BCGS-FFT method, first order divergence conforming basis functions are used for flux densities and second order curl conforming basis functions are used for vector potentials. Therefore, boundary conditions of both flux densities and vector potentials are satisfied. Moreover both dielectric and magnetic contrasts can be taken into account since no zero terms are produced due to the divergence and curl operations in the integral equations. Examples will be shown to validate the effectiveness of the mixed order BCGS-FFT method on anisotropic and/or magnetodielectric objects.