Abstract

The FDFD-electromagnetic model computes wave scattering by directly discretizing Maxwell’s equations along with specifying the material characteristics in the scattering volume. No boundary conditions are needed except for the outer grid termination absorbing boundary. We use a sparse matrix Matlab code with generalized minimal residue (GMRES) Keyespace iterative method to solve the large sparse matrix equation, along with the Perfectly Matched Layer (PML) absorbing boundary condition. The PML conductivity profile employs the empirical-optimal value from [4-6].

The sparse Matlab-based model is about 100 times faster than a previous Fortran-based code implemented on the same Alpha-class supercomputer. The 3D FDFD model is easily manipulated, it can handle all types of layer-based geometries if the target region is less than 25% of the total computational space.

Several cases have been investigated. The scattered electromagnetic fields due to spherical and elliptical target-like TNT targets buried in simulated Rosman soil are computed and compared to reference solutions. The field distribution of dipole in the half space is computed and compared to the half-space Born approximation forwarding Model [8].

Opportunities for Technology Transfer

- Conventional techniques versus our approach
- 3D Matlab-based FDFD model is implemented in our program – compared with other software programs.
- Technology Transfer
- The general purpose of this research is detecting the subsurface targets according to their EM properties. The model can be applied to the real world in the oil field by the induction or reflection imaging methods. The geometry for well logging is commonly anisotropic multi-layered & multi-structured structure, which is suitable for the proposed model.
- This model can also be applied to other fields such as mine detection and tensor detection with the corresponding high and low frequencies.

3D FDFD Modeling

3D matlab-based FDFD (finite difference frequency domain) method :

- Based on the general Maxwell’s equations, the wave equation is given by

\[ \nabla \cdot \left( \sigma \nabla \phi \right) = 0 \]

where \( \sigma \) and \( \phi \) are the conductivity and electric potential, respectively.
- Equipped with the popular PML (perfectly matched layer) ABC (absorbing boundary condition).
- Employing the FEM cell geometry as the grid structure of finite difference method.

3D FDFD Modeling

- The applying mathematical method

The method finally leads to solving the problem of matrix equation: \( A = B \), where \( A \) is the coefficient matrix, \( B \) is the source column matrix and \( s \) is the unknown. \( s \) is a very large sparse matrix. Therefore the problem is suitable for the Keylokeyev subspace iterative methods. One of them, GMRES method, is used after solving the structure of matrix \( A \) by multiplying the assimilated matrix and doing some permutations.

III. Comparison to BAFM method

Geometry and Parameters:
- Interface located at \( z = 0 \) with air above
- The operating frequency is 1GHz
- Wet soil with relative dielectric constant \( e = 20 + i 0.06 \)
- The dipole with \( x \) polarization located \( 5 \) cm below the interface.

The magnitude and phase distribution of \( E_x \) components at plane \( x = 0, y = 0 \) and \( z = 0 \) from FDFD and SAMM.

Conclusion:

The CPU time and memory used in the modified FDFD model are much less than those of the previous model. It is practical in some sort.

Analysis

The comparison between modified FDFD method and SAMM method agree very well. In the modified FDFD model, the total iterative number is 241, the CPU time is about 123 minutes (it is around 20 hours previously), the relative residue goes down to 0.07 (the previous one is around 0.22), the iterative memory is 3.70 (the previous is around 10G). Therefore, in this case, the modified FDFD method is indeed improving considering the CPU time, the memory even the performance from the previous model.