ELECTROMAGNETIC WAVE THEORY AND APPLICATIONS

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Analytic and Monte Carlo Studies on Electromagnetic Interactions with Nonspherical Dense Media

Sponsor
National Science Foundation
Contract ECS-9615799

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Monte Carlo simulations are used to derive the effective permittivity of a random medium consisting of densely packed spheroids. Previously, characterization of the effective permittivity has been performed for the 2-D case and for collections of spheres but not for 3-D collections of spheroids. In this work, effective permittivities are derived using the coherent field method. The coherent-field method involves finding the average scattered field over many realizations from a collection of scatterers contained in some predetermined boundary, and comparing those results to scattering from a homogeneous medium of the same size and shape. Using this method, the effects of boundary shape and size are taken into account directly. In addition, the effective permittivity is calculated directly. We compared scattered intensities from two cases: 1. scattering from a collection of randomly distributed spheroidal particles contained in some predetermined boundary, and 2. scattering from homogeneous media contained of the same shape. Results are compared with classical mixing formulas and are found to be in good agreement, especially at low fractional volumes where the independent scattering approximation is more valid. At higher fractional volumes, multiple scattering effects become stronger, and the real part of the effective permittivity becomes larger than that predicted by classical mixing theories.

Electromagnetic Radiation, Propagation and Scattering in Complex Media

Sponsor
Office of Naval Research
Contract N00014-92-J-4098

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Low-frequency electromagnetic induction (EMI) sensors are useful in detecting subsurface metallic objects. However, discrimination of targets based on their EMI responses is considerably more complex. To understand how the response depends on the geometry of the target, it is desirable to have at our disposal the analytical solutions of a few canonical shapes. The spheroid is especially useful as a prototypical model for elongated targets. We consider a conducting and permeable spheroid excited by a uniform time-harmonic magnetic field with arbitrary direction. The surrounding medium is assumed to be poorly conducting so that its wavenumber can be considered to be zero. Thus solutions for the Laplace equation can be used outside the spheroid. Inside the spheroid, the magnetic field satisfies the vector wave equation (with the squared wavenumber being imaginary). To solve the problem, we expand the field inside the spheroid in terms of the vector spheroidal wave functions and impose continuity of tangential **H** field and normal **B** field at the surface of the spheroid as boundary conditions. An infinite system of equations for the expansion coefficients is obtained, which are solved numerically by truncating the system.

Analysis of Electromagnetic Interaction

Sponsor
Office of Naval Research
Contract N00014-97-1-0172

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We develop a hybrid SPM/MoM technique to calculate the EM scattering from a 3-D conducting object above a rough surface. In this hybrid technique, the Green's function and surface variables are expanded in terms of the surface height function on the mean surface, and the electric integral equations based on the extinction theorem and the surface boundary conditions are decomposed into different orders. Each order represents a flat-surface scattering problem with the same geometry and different equivalent sources, so that it can be solved efficiently by using the dyadic Green's function for layered media as discussed in the previous chapter. The separation of the solution into different orders also helps us identify and characterize the individual interaction terms between the object and the rough surface.

Mine and UXO Detection Based on Enhanced Signatures Using Angular Correlation Function

Sponsor
MIT Lincoln Laboratory
Agreement BX-6841

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A model for the electromagnetic induction (EMI) response of a collection of small conducting and permeable objects was developed. In this model each object is characterized by its magnetizability tensor which gives the response to a locally uniform primary field. Including the multiple interactions between the objects a system of linear equations is established which allows solving for the induced magnetic dipole moment of each object in response to an externally applied primary field.

As the basis of a library of magnetizability tensors of canonically shaped objects the classical solution for a conducting and permeable sphere was analyzed and implemented numerically. A novel approximate solution for a solid cylinder of finite length was developed and investigated both theoretically and numerically. A problem with this approximation for axial primary fields and large permeability motivated the solution of the problem of the axial excitation of a prolate spheroid based on scalar spheroidal wave functions. Simultaneously we are also developing the solution of the problem of the arbitrary excitation of a prolate spheroid based on vector spheroidal wave functions. Carrying out a comprehensive literature survey showed that these mathematically quite complex spheroid solutions are not documented elsewhere.

Another topic of theoretical investigation has been the consideration of statistically oriented objects subject to an externally applied primary field. In this electromagnetically more simplistic approach the mutual interaction and spatial distribution of the scatterers is ignored which enables obtaining analytical expressions of the mean response for distributions such as a uniform distribution in polar angle and uniform distribution in solid angle of the orientation of identical elongated objects.

Computational Technique for EM Propagation in 3-D Periodic Structures

Sponsor
MIT Lincoln Laboratory
Agreement CX-27584

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In this research the oblique incidence Finite-Difference Time-Domain technique for periodic surfaces is used to calculate the transmission characteristics of an infrared bandstop photonic crystal filter. The relation between the bandwidth and filling fraction of the unit cell is studied by the variation of design parameters. The mechanisms of the dual stopbands are investigated. The separation between the layer and the relative size of the metal patches determines the position and bandwidth of the lower stopband, and the periodicity across the same surface determines the position of the upper stopband. A higher metal filling fraction also enhances the bandwidth. The knowledge gained was used to design a bandstop filter for the bands 3-5 micro meters and 8-12 micro meters. The transmission coefficient in the main stopband (8-12 micro meters) is below –10 dB. Scattering coefficients are calculated for different incidence angles, and the stopbands are shown to exist for different angles of incidence.

Inverse Scattering Models for Recognition of Target under Foliage

Sponsor
MIT Lincoln Laboratory
Agreement BX-6807

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In this research, a three-dimensional FD-TD simulation is presented which models the scattered field of an object in or beneath a layer of foliage. The FD-TD computational domain contains three layers: free space, a foliage layer, and a homogeneous layer that may also contain the object. Strong fluctuation theory is used to model the discrete scatterers (leaves, vegetation) in the foliage as an effective permittivity with a random spatial variance. The foliage can then be replaced with a random permittivity that fluctuates from cell to cell, described by a correlation function that is Gaussian in the horizontal direction and exponential in the vertical direction. Parameters such as the scatterer's permittivity as well as the horizontal and vertical correlation lengths have been previously determined by matching theoretical models with experimental data. In addition to the foliage, tree trunks will also be modeled using dielectric cylinders created with a conformal mapping technique. Both the homogeneous and the random layers are lossy, so a modified PML with stretched coordinates is used to terminate the computational domain. The simulation assumes a TE or TM plane wave incidence, and uses a total/scattered field formulation for stratified media. The near to far field transformation is performed by enclosing both the object and random media in a Huygen's surface, and integrating the equivalent frequency domain electric and magnetic currents with the layered Green's function. Monte-Carlo analysis is performed using an ensemble of random media whose parameters appropriately describe various models of vegetation. Each realization of the random media is generated in the spatial frequency domain by filtering random numbers (with zero mean and normalized variance) with the Fourier transform of the correlation function. A three dimensional Fast Fourier Transform is then used to generate the spatial fluctuation, which is mapped into the FD-TD computational domain. The statistical properties of the scattered field will be studied using the numerical simulation technique developed in this work.

Research on SAR simulation model

Sponsor
Mitsubishi Corporation
Agreement MECA0823
Agreement MECA0824

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We develop the image processing scheme of the synthetic aperture radar (SAR) based on the integration of backscattering coefficient in time domain. With the far field approximation and by considering the scatterers as non-dispersive media, the range and cross-range parameters are decoupled and the integral ends up with a closed form function. As a result, the SAR image simulation based on the analytical process largely increases the computational efficiency and makes it possible to process large size of images. In the simulation, the geometrical optics approximation is used to model rough surface scattering of the terrain specified by the digital elevation map (DEM). It is shown that the integral process of the SAR image in time domain can be derived into frequency domain to yield the integral of the scattered field over the bandwidth. Therefore dispersive scatterers can also be modeled by including an additional integration over the bandwidth.

Polarimetric passive remote sensing

Sponsor
Office of Naval Research
Contract N00014-99-1-0175

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We model the foam as a volume with thin-film water bubbles. The radiative transfer (RT) equations are set up in this volume with the boundary conditions linking the atmosphere and the ocean surface. The RT equations in the foam layer are solved by using an iterative method, and a closed form solution is obtained up to the first order. In the solution of the RT equations in the foam layer, the terms provide the physical meaning of the wave propagation and interaction between the atmosphere and the water bubbles in the foam. For the interface of the atmosphere and the open ocean surface, thermal emission is the sum of the reflection of down-going atmospheric thermal emission and the thermal emission from the plain ocean surface. The total thermal emission at the radiometer is the sum of the contribution from the atmosphere-foam interface and the atmosphere-plain ocean surface interface, weighted by the foam coverage. In the one-scale model, in which only the small-scale ocean waves are taken into account, we find that the atmospheric thermal emission is comparable to the foam's thermal emission for the co-polarized waves. The two-scale model is more realistic in comparison with the one-scale model, however it requires much more computational time since two more folds of integration are needed for averaging over the slope of large-scale ocean waves.

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