3D VECTOR ELECTROMAGNETIC SCATTERING FROM MULTILAYER RANDOM ROUGH SURFACES USING STABILIZED EBCM FOR REMOTE SENSING OF SOIL MOISTURE

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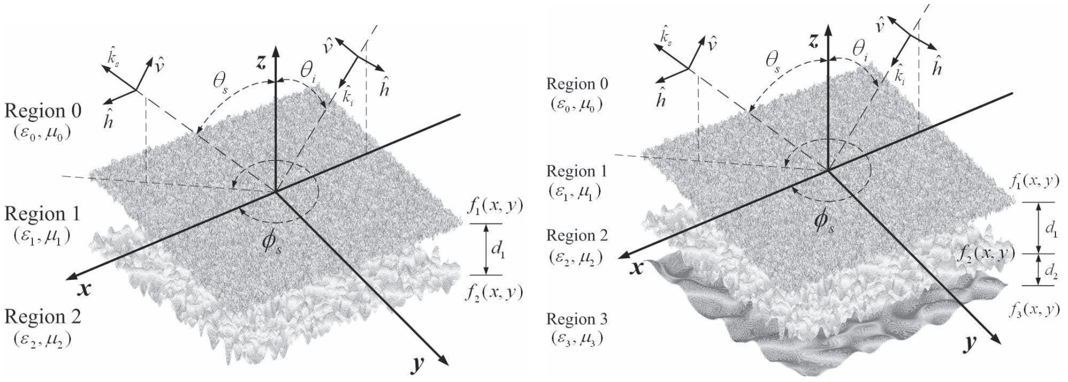
1. INTRODUCTION

The problem of electromagnetic scattering from arbitrarily random rough surfaces has been a subject of great interest over the past several decades for its important applications in microwave remote sensing. Being representative of many naturally occurring surface and subsurface structures such as soil, snow, and ice, the forward scattering model from single or multiple-layered random rough surfaces gives indispensable knowledge of the interaction between electromagnetic waves and these remote sensing targets. Currently, one of the major applications of radar technology is to map the distributions of soil moisture whose temporal and spatial variations are key parameters in climatic and hydrologic models. With the recent development of low frequency radar systems, e.g., at UHF and VHF bands, the capability of probing deep and root-zone soil moisture is significantly enhanced due to the large penetration depth of the electromagnetic waves. Studying the scattering properties of soil at subsurfaces requires an accurate and efficient microwave scattering model which involves multilayer rough surface structures and inhomogeneous dielectric profiles. Due to the extremely large computational load for solving the electromagnetic scattering from two-dimensional rough surfaces using numerical techniques, current applicable solutions are mainly analytical and based on approximation techniques[1], e.g., small perturbation method (SPM), Kirchhoff approximation (KA), and small-slope approximation (SSA). Though these methods have very high computational efficiency, their validity domains are limited to surfaces having either small roughnesses or large radius of curvature, and the combination of these methods cannot cover the entire range of practical problems. In order to be able to accurately analyze the scattering from surfaces with arbitrarily roughness at comparably high computational efficiency, our work is concentrated on a solution using the extended boundary condition method (EBCM). Previously, we have solved and presented the bistatic scattering solution from a single surface [2], which plays a basic and important role in the solution to the scattering problem from multilayer surfaces. The solutions in [2] show good agreements with results given by available analytical (SPM, KA and SSA) and numerical methods (Method of Moments (MoM)) within their respective validity regimes. However, the previous model failed when being applied to surfaces with larger standard deviations and loss due to the instability of the classical EBCM [1]. We have solved this instability problem and extended the range of validity of the solution substantially for a single rough surface (see our concurrent paper titled ‘Electromagnet Scattering from arbitrary random rough surfaces using Stabilized Extended Boundary Condition Method (SEBCM) for Remote Sensing of Soil Moisture’). In this work, the single-surface model is used as a building block to develop the solution for double-layered and multilayer scenarios using SEBCM. Validation of this multilayer rough surface scattering solution can be done by comparing with the results from SPM and MoM. Development of this model will also enable quantitative comparison between theoretical analysis and actual radar measurements of soil moisture. Importantly, it will also serve as a forward solver in the inverse model for soil moisture microwave remote sensing application in the future.

2. PROBLEM GEOMETRY AND APPROACH DESCRIPTION

Firstly, the problem of 3D bistatic scattering from surfaces with two random rough interfaces is shown in Figure 1(a). The 2D rough surface f_1 separates the free space (region 0, ϵ_0, μ_0) from a homogenous medium (region 1, ϵ_1, $\mu_1 = \mu_0$), which fills a layer of thickness d_1. The bottom of this layer presents another rough surface f_2. Below f_2 is the lower half space of homogenous medium (region 2, ϵ_2, $\mu_2 = \mu_0$). Similarly, geometry of 3D bistatic scattering from surfaces with three arbitrary random rough interfaces is shown in Figure 1(b), where a second layer of thichness d_2 is separated from the lower half medium by a third surface with profile f_3. Thus, the space is divided into four regions in total. Geometry of scattering from surfaces with more rough interfaces can be formed in the same fashion.



(a) two-layer geometry

(b) three-layer geometry

Figure 1. Problem geometries.

As solving a single-surface scattering problem, the scattering matrix of each rough surface is computed using SEBCM. By expressing the propagating waves in terms of a superposition of Floquet modes and matching the extended boundary conditions on test surfaces in each region separated by the actual surface, a matrix system can be constructed to solve the unknown electric and magnetic current sources at the actual surface and further to derive the scattered fields, thereby, to obtain the scattering matrix. Locations of test surfaces in each region are restricted and controlled explicitly by z-coordinate transformations, which will stabilize the overall matrix system. The so-called k-chart, which is the arrangement of the Floquet modes in k-space, of each surface can be optimized depending on the dielectric properties of each region. Together with the scattering matrix of each medium layer inbetween every two surfaces, which is a diagonal matrix consisting of propagation factor in each mode, all scattering matrices are cascaded to obtain the scattering matrix of the whole multilayer structure. Moreover, for a rapid increment of matrix computations resulting from the increasing number of layers, other numerical optimizations, e.g., algorithm based on blocking, are necessarily implemented.

Validation of the 3D multilayer SEBCM model can be done by comparing with SPM solutions within small roughness regimes. For larger roughness, the most persuasive validation will be through field measurements using our tower-based radar, along with in-situ soil moisture sensors for direct validation of the moisture and dielectric profiles.

3. FUTURE WORK

Ongoing work includes further optimization and enhancement of the computational efficiency by adapting the algorithm on graphics processing unit (GPU), which has more suitable architecture for matrix operations involved in the SEBCM. This in turn will make the technique more readily suitable for use in inverse models for retrieval of root zone soil moisture. Extensive radar field experiments are planned for direct validation of simulated results.

4. REFERENCES

[1] Jin Au Kong, (1990), *Electromagnetic Wave Theory*, John Wiley & Sons, Inc.

[2] X. Duan, M. Moghaddam, ‘Full Wave Vector Electromagnetic Scattering from Two-Dimensional Arbitrary Random Rough Surfaces,’ *IEEE International Symposium on Antennas and Propagation*, Charleston, SC, June 2009.