RETRIEVAL OF SUBSURFACE PARAMETERS FOR THREE-LAYER MEDIA

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1. INTRODUCTION

Many environmental, industrial, military, geological, and civil engineering applications require fast and accurate non-contact estimation of parameters of subsurface structures, possibly with multiple non-smooth layers. These applications include estimating the depth of bodies of fresh water, through-the-wall imaging, detecting buried objects, and estimating root-zone soil moisture and composition. The penetrating abilities of low frequency radiation make it a good candidate for this group of applications, provided sufficient resolution can be achieved. Since the radar measures the scattered fields which are proportional to the radar cross section of the targets, an efficient inversion methodology is needed to obtain the sought-after parameters from the scattering measurements. Most inversion algorithms require multiple iterative evaluations of a forward scattering model. Therefore, an efficient forward model with a large region of validity is crucial for the success of the inversion. In this work, we use a recently developed forward model that satisfies these criteria, and is optimized for application to media where the top interface is approximated as a periodic surface, while the bottom is treated as a random rough surface. The dielectric properties and surface height scales are assumed arbitrary. This model would apply, for example, to bodies of fresh water, desert sand, and adobe walls. The forward scattering algorithm is based on the extended boundary condition method (EBCM) and scattering matrix technique, and has been reported previously. The inversion algorithm is implemented as a sequential Newton-type optimizer, using a multidimensional closed-form equivalent of the forward solver.

2. FORWARD MODEL

The scattering from the target 3-layer 2-interface medium is solved using EBCM and cascaded scattering matrix techniques. First, discrete Floquet modes are generated for the top periodic surface. Then, a period is assigned to the bottom random rough surface, which equals an integer multiple of the period of the top surface, and used to generate the Floquet modes for this lower interface. Finally, the modes are matched to obtain the overall transition matrix for the system and to calculate the scattering cross sections.

3. INVERSION OVERVIEW

Even though the computational complexity of this forward model is significantly less than a fully numerical routine such as the Method of Moments (MOM), it is still too costly for use in an iterative inversion algorithm. To make the model more suitable for inversion, the full model is simulated for a range of parameters such as dielectric constant, surface statistics, and layer separation. Then, the dependence on each of these parameters is sequentially modeled using much simpler, analytically differentiable functions, such as multidimensional polynomials or transcendental functions. Once the closed-form model is developed, the subsequent evaluations of the forward model are extremely fast and the forward model is suited for both local and global inversion techniques. The inversion process requires at least as many independent data points (measurements) as there are unknown model parameters.

4. SEQUENTIAL LAYER CHARACTERIZATION

In practice, the initial overhead cost of simulating the function for a range of values of all of the unknowns may be too large to be practical. Therefore, a sequential layer characterization algorithm is applied. Assuming the medium between the first and second interfaces is lossy, the scattering problem is simulated at a sufficiently high frequency such that the effect of the 2nd interface is negligible. Since only the top layer affects the cross section coefficients the number of unknowns is reduced to three: the period of the surface, its amplitude, and dielectric constant of the 2nd layer. A periodic interface is deterministic and non-random so only one realization of the interface is needed. Thus, from a computational point of view it is advantageous to retrieve the permittivity of the 2nd layer from the periodic interface, not from the rough 2nd interface.

5. PERIODIC AND ROUGH INTERFACE CHARACTERIZATION

For a sinusoidal interface, the bistatic scattering coefficient is nonzero only at a few discrete angles. This makes it difficult to fit a well behaved function to the cross section. These angles at which scattering coefficients are nonzero only depend on the ratio of the period of the sinusoidal surface and the wavelength. Therefore, the retrieval of this parameter can be done separately by means of searching. After determining the period of the top surface the remaining two parameters of the periodic surface are retrieved using the function-fitting method described above. The procedure is repeated at a low frequency to recover the parameters of the lower interface. This algorithm allows the number of evaluations of the full EM model to be significantly reduced. While the direct method requires the number of forward model evaluations to be equal to the product of the number of simulation points for both layers, the new algorithm reduces the total number to just the sum of the two.

6. RESULTS AND CONLCUSION

Several cases have been simulated and retrievals validated. The range of applicability and sensitivity to various parameters will be discussed at the talk. The algorithm is efficient and scalable to more parameters and interfaces. The method can be easily modified for problems requiring two rough interfaces, periodic-below-rough interface, or periodic surface with a roughness superimposed on it on top of the rough interface. The approach is flexible and can be applied to many real world problems.

6. REFERENCES

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