Inversion of Electrical and Geometrical Parameters of a Structure with a Rough Interface

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ABSTRACT

This study presents the characterization of rough surfaces, based on the small perturbation method (SPM) and the small slopes approximation model (SSA). The inversion problem is then formulated as a cost function optimization problem and is solved using a global optimization algorithm known as simulated annealing (SA). The examples of analysis and inversion shows that this inverse method is feasible and efficient using the algorithm of simulated annealing.

Keywords: Rough surfaces, Direct problem, Inverse problem

1 Introduction

One of the objectives of active microwave remote sensing is the analysis of the radar echo collected afterits interaction with the surface of the earth. From this radar signature, we seek to obtain information onthe electrical and geometric parameters of the observed scene. To better understand this inverse problem, a good knowledge of the direct problem remains essential. For the direct problem we use the small Slope Approximation model (SSA) and the small Perturbation Method (SPM). reported in [1], to calculate theelectromagnetic wave scattered from a layered rough surface. The complex dielectric constants (the relative permittivity), the layer thicknesses and the statistical properties of the interfaces are the unknowns of thereverse diffusion problem. The resolutions of the inverse problem represent the recovery of rough surface parameters from backscattered data.

2 Invers problem

The goal in any inverse problem is to determine a vector of unknown parameters. The vector $\boldsymbol{x}$ of the unknowns of the problem, namely the electrical parameters (ε_{r1}, ε_{r2}) and geometrical parameters of the interfaces (quadratic height σ_{s1}, σ_{s2}, correlation length lc_1, lc_2 and layer thickness u_0).

We use the cost function to be minimized based on the ratio of the layered rough surface index by [2]:

$$f_{coût}(\boldsymbol{x}) = \frac{1}{N_\theta N_f}\sqrt{\sum_{i=1}^{N_\theta}\sum_{j=1}^{N_f}\left|\frac{1}{\rho^{(th)}_{b'a',ba}(\boldsymbol{x}, f_j,\theta_i)+1} - \frac{1}{\rho^{(\exp)}_{b'a',ba}(f_j,\theta_i)+1}\right|^2} \tag{1}$$

We also use the intensity cost function defined by [3]:

$$f_{coût}(\boldsymbol{x}) = \frac{1}{N_\theta N_f}\sqrt{\sum_{i=1}^{N_\theta}\sum_{j=1}^{N_f}\left[\left(\frac{I^{(th)}_{ba}(\boldsymbol{x}, f_j,\theta_i) - I^{(\exp)}_{ba}(f_j,\theta_i)}{I^{(\exp)}_{ba}(f_j,\theta_i)}\right)^2 + \left(\frac{I^{(th)}_{b'a'}(\boldsymbol{x}, f_j,\theta) - I^{(\exp)}_{b'a'}(f_j,\theta_i)}{I^{(\exp)}_{b'a'}(f_j,\theta_i)}\right)^2\right]} \tag{2}$$

The simulated annealing scheme used in our study is based on the algorithm of Corana *et al* [4]. In [1] we modified the Corana algorithm in order to get it out of a local minimum towards which the algorithm converged. We consider bi-static multi-frequency radar configurations. We use six L-band frequencies:

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$f_1 = 1$, $f_2 = 1.2$, $f_3 = 1.4$, $f_4 = 1.6$, $f_5 = 1.8$ and $f_6 = 2$ GHz, and the angles of measure as $\theta_1 = 30°$ and $\theta_2 = 45°$. The study is applied to a structure representing a soil formed of layers with different humidity (volumetric water content 15% and 20%) which corresponds to the following relative permittivity values: $6.26 - 0.52j$ and $8.45 - 0.85j$ for the 1 GHz frequency [5]. We use $\varepsilon_r = \varepsilon_r' - j\sigma / (2\pi f \varepsilon_0)$, for the relative complex dielectric constant ε in the case of frequency change. We consider isotropic interfaces. The elements of the vector $\boldsymbol{x}$ and these limits $\boldsymbol{LB}$ and $\boldsymbol{UB}$ are summarized in Table 1:

Table 1: *Real values of electrical and geometric parameter, lower and upper limits of the parameter vector. The geometric parameters ere expressed in cm.*

	ε_2'	σ_2	ε_3'	σ_3	u_0	lc_1	σ_{s1}	lc_2	σ_{s2}
LB	3	0	3	0	0.1	0.01	0.0	0.01	0.0
UB	15	0.2	15	0.2	1	0.25	0.05	0.25	0.05
Real value	6.26	0.04	8.45	0.07	0.5	0.1	0.02	0.1	0.01

3 Inversion result

The global procedure of the inversion is divided into two parts, the first is considerably simplified in thecase where the minimization is done on the real and imaginary parts of the permittivity's of the media and the thickness of the structure, i.e. in the end 5 parameters of where the use of the cost function (1), the second a little complicated where the minimization is done on all the dielectric and geophysical parameters (Table 2), that is to say on 9 parameters, hence the use of the cost function (2). Tables 2 gives the inversion results using the two methods SPM and SSA with the cost function (1) and (2) respectively. The results obtained show the use of the SPM method is more efficient from the point of view of the values of theparameters as well as the execution time compared to the SSA method, this comes down to the fact thatthe expression of the incoherent intensity in SSA is more complex than that in SPM, which requires a longer computation time.

Table 2: *Result of inversion for five variables with and for nine variables*

	5 variables	***9 variables***
SPM	*4.6×10^{-05}*	*15 minutes and 32 seconds*
SSA	*2.5×10^{-05}*	*20 minutes et 25 seconds*

4 Conclusion

As a comparison between the calculation methods of the incoherent intensities, we used the SPM method and the SSA method. We used two cost functions to be minimized by the simulated annealing algorithm to recover to the parameters characterizing a stratified structure with two correlated and isotropic rough interfaces. The presented inversion results show that the SPM method is more efficient from the point ofview of the parameter values as well as the execution time compared to the SSA method, Simulated annealing is a powerful optimization algorithm for estimating the subterranean properties.

How to Cite

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