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Microwave Scattering for Soil Texture at X-Band and Its Retrieval Using Genetic Algorithm

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Abstract

In the present paper, we have studied the effect of soil textures, *i.e.*, sand, silt and clay on microwave scattering at X-band (10 GHz) at various incidence angles and like polarizations (*i.e.*, Horizontal-Horizontal; HH-, Vertical-Vertical; VV-). We have proposed a retrieval technique based on Genetic Algorithm (GA) to retrieve soil texture. For this purpose, ten types of soil mixtures having different percentage of sand, silt and clay have been analyzed. The observations were carried out by ingeniously assembled X-band scatterometer. A good agreement has been noticed between estimated and observed soil texture. Study infers that soil texture is quite sensitive to radar scattering and it is possible to retrieve soil texture with radar/scatterometer data with good accuracy and this type of retrieved results can be helpful to predict soil strength as well as soil erosion of the particular area.

Keywords

Soil Texture, Retrieval, Microwave Remote Sensing

1. Introduction

Nowadays it is quite interesting task to monitor the Earth's surface because it represents an essential part of the ecosystem. One of the important elements of the Earth's surface is soil. Soil can be parameterized by various

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ways but for radar remote sensing it can be parameterized in terms of its dielectric and geometric properties. The dielectric properties of the soil are expressed by its composition (soil texture) and moisture whereas the soil roughness describes the geometric properties of the soil surface [1]-[4].

The knowledge of soil texture is important for the various applications like study of soil erosion, soil strength, generation of the soil texture map for land use planner etc. [5] [6]. According to United States Department of Agriculture (USDA) soil can be classified in terms of the percentage of Sand, Silt and Clay. Sand, Silt and Clay are classified in terms of their size as shown in **Table 1** [7]. The relative percentage of these size based categories, determines the soil's textural class (*i.e.* loamy, silt loamy etc.). Change in the soil textural class can determine the soil strength and erosion properties [5] [6].

Generally, people are using the classical methods in soil physics which is based on point measurement to estimate these ground surface (*i.e.*, soil) parameters. These methods are very cumbersome and take a lot of time. However, remotely sensed (from space or airborne sensors) information provides new opportunities to hydrologists and ecologists to study soil characteristics for large region with spatial resolution from a meter scale to a global scale [8]-[12]. Therefore, it is important to critically analyze various remote sensing techniques so that suitable technique may be selected for retrieving various Earth's surface parameters. In this regard, radar remote sensing with its sensitivity to the dielectric and geometric characteristics of objects, its weather independent imaging capability and its potential to acquire subsurface information, is one of the most promising approaches for the surface parameter estimation [1] [3] [4] [8]-[10]. Therefore, in this paper an attempt has been made to study soil texture with microwave scattering and we have proposed a retrieval algorithm to retrieve soil texture, which can be considered as a powerful technique to access soil texture with remotely sensed data.

Several researchers since last many decades are studying the electromagnetic wave scattering on rough surfaces [2] [3] [13]. Many experimental measurements related with Scatterometer have been accumulated and many approaches have been developed in order to predict and interpret experimental data. Several moisture and surface parameter retrieval methods are listed in the literatures [1] [4] [8]-[19]. Various physical models (*i.e.*, Physical Optics, Small Perturbation Model (SPM), Kirchhoff Approximation) are available which are directly related to the radar scattering and soil parameters like soil moisture and roughness but these models need a lot of inputs or a priori information to retrieve soil parameters [2]. Second type of modelling approach that is called semi-empirical approach [4] [8] [19] is used to overcome some of the limitations of theoretical models.

All these theoretical, semi-empirical and empirical models utilize either three datasets (HH, VV and HV) or two datasets (HH and VV) and subsequently these models are used to invert a few parameters that depend on number of the datasets used. With the need of retrieval of more parameters with the less number of datasets, search of the optimization techniques started. The optimization techniques, generally used by researchers, are Artificial Neural Networks (ANN), Genetic Algorithms (GA), Particle Swarm Optimization (PSO) and many others. The ANN method always takes a large amount of data and long time to train the network whereas genetic algorithm (GA), which is based on the principle of optimal selection in natural evolution process, has been widely applied to optimization problems in engineering [13] [19]-[22]. In remote sensing, GA is used for the retrieval of the multi parameters, *i.e.*, soil moisture, roughness and other soil constituents.

A lot of work has been done for the retrieval of moisture contents and surface roughness but very few works has been reported for estimation of soil texture with radar approach. The soil texture is the field in which advancement and more research is required. To retrieve soil texture, *i.e.*, percentage of sand silt and clay, we should relate soil texture to dielectric constant of the soil. The dielectric constant of soil is related to the scattering coefficient. Therefore, by the use of effective optimization technique, soil texture constituents can be retrieved. Therefore, in this paper, microwave scattering properties have been observed for various soil textures at X-band using ingeniously designed Scatterometer. Results of this study are further used to develop soil texture retrieval algorithm using GA. This paper is organized as follows. Section II explains the field measurements

Table 1. Particle size classification of soil.

Type of soil constituent	Particle Size (mm)
Sand	2 - 0.05
Silt	0.05 - 0.002
Clay	<0.002

followed by Section III which describes experimental procedure and various field data observed. Modelling approach to retrieve soil texture has been developed in Section IV. Section V deals with results and discussion part which discusses modelling approach in detail and Section VI concludes with final remark.

2. Field Measurements

The soil moisture was calculated by taking the soil samples randomly from five points in the Sandpit. These soil samples were weighted and dried at 110˚ for one day and then the weight of the dried soil is measured. The volumetric soil moisture is calculated as follows

$$m_v = \frac{\text{Weight of moist soil - Weight of dry soil}}{\text{Weight of dry soil}} \times \rho_b \quad (1)$$

where ρ_b is soil bulk density.

Surface roughness measurement profiler was used to carry out the surface roughness measurement. Some points are sampled on the rough surface and data was collected to make a graphical estimation of the replica of the surface. Root-mean-square (RMS) surface height was measured with this replica.

Sieve analysis and hydrometric test were carried out for the measurement of soil particle size. The detailed experimental procedure is provided in [23]. The percentage of sand, silt and clay for different soil texture field was decided based on sieve analysis and hydrometric test.

3. Experimental Procedures and Field Data

The observations were carried out by ingeniously developed X-band scatterometer and details of scatterometer are given in [14]-[17]. Ten bare soil plots (P1 to P10) of dimension 2.5 m × 2. 5 m with different soil textures, constant RMS surface heights and constant soil moisture content were taken for development and testing of algorithm. The scatterometer setup is designed for measurement of scattering coefficient at X-band (10 GHz) for co-polarizations (HH-Pol and VV-Pol) and incidence angles from 30˚ to 70˚ by 10˚ steps. The average volumetric soil moisture content of these plots was measured as 0.06 $cm^3 \cdot cm^{-3}$, *i.e.*, the soil fall in dry category, which was taken approximately same for all plots.

4. Model Development

A modelling approach for retrieving soil texture using genetic algorithm is shown in the **Figure 1**. The following steps were carried out to implement the proposed algorithm for retrieving soil texture.

Step 1: Scattering coefficient was observed for 10 different soil texture fields keeping soil moisture and surface roughness constant. Observations were carried at different incidence angles and in HH- and VV-pol. An

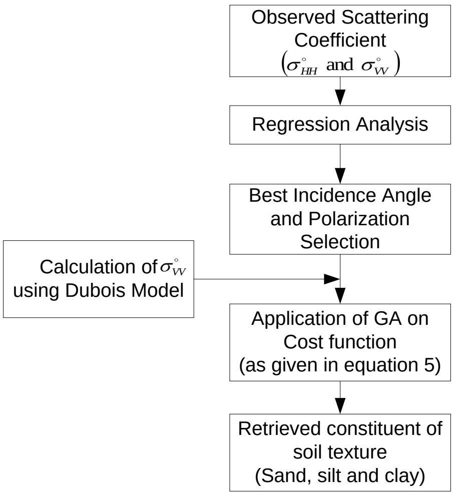

Figure 1. Modeling Approach to retrieve soil texture using genetic algorithm.

analysis was carried to observe the change in scattering coefficient with the change in sensor parameters, *i.e.*, incident angle, polarization and target parameters, *i.e.*, soil texture. Significant changes in scattering coefficient were observed for the change in sensor parameters as well as target parameters.

Step 2: Regression analysis was carried out to select best incidence angle and polarization based on R^2 values. It was observed that scattering coefficient at 70˚ in VV-pol provide best R^2 value. Therefore, this scattering coefficient value was used for retrieval of soil texture.

Step 3: A cost function was developed for retrieval of soil texture, *i.e.*, sand, silt and clay. Dubois model [3] was used as theoretical model that will provide theoretical scattering coefficient for optimization of cost function.

Step 4: Genetic Algorithm (GA) was applied on developed cost function to evaluate sand, silt and clay percentage in soil. Theoretical scattering coefficient and observed scattering coefficient were used in the optimization of cost function with GA. GA, originally developed by Holland, is efficient to solve various combinatorial optimization problems [13] [19]. They are stochastic search approaches based on randomized operators, such as selection, crossover and mutation. For the present work, Continuous Genetic Algorithm (CGA) has been used to optimize the percentage of sand, silt and clay in the soil.

5. Results and Discussion

5.1. Behavior of Scattering Coefficient for Different Soil Texture Field

With the use of the measurement setup, the scattering coefficient was observed for ten different type of soil texture. The incidence angle and polarization are quite sensitive to soil texture, which is examined by the experimental results. **Figure 2** and **Figure 3** show angular variation of scattering coefficient for HH- and VV-pol respectively for five different bare soil surfaces with RMS height approximately equal to 0.5 cm and volumetric soil moisture content was 0.06 $cm^3 \cdot cm^{-3}$.

The percentage of gravels was approximately same for first five fields (P1 to P5) whereas a good variation in percentage of sand, silt and clay among all five fields were prepared. The average dynamic range in scattering coefficient with incidence angle was 6.8 dB and 13.8 dB for HH- and VV-pol respectively for all plots. VV-pol shows wider dynamic range of σ°, therefore this polarization may be used for assessing the texture of soil more precisely due to its wider dynamic range in comparison with lesser dynamic range of HH-pol.

It is observed in **Figure 2** (HH-pol) that the average dynamic range of σ° with angle of incidence is maximum for plot 5 and minimum for plot 1. In plot 5, the percentage of sand and percentage of silt is approximately

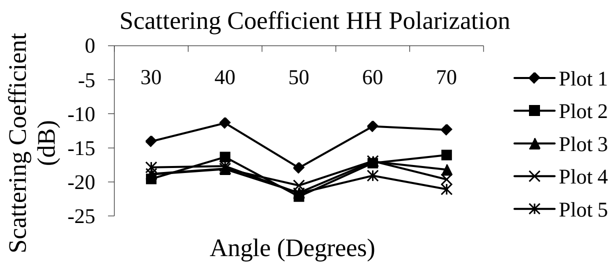

Figure 2. Angular variation of scattering coefficient for various mixtures for HH Polarization at X-band.

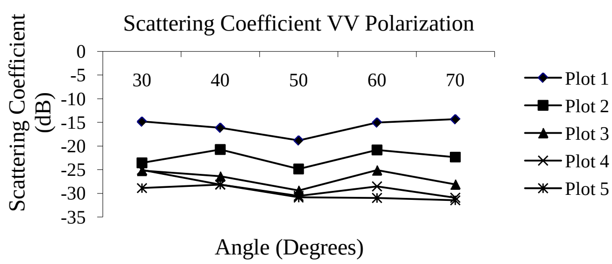

Figure 3. Angular variation of scattering coefficient for various mixtures for VV Polarization at X-band.

same whereas in plot 1 percentage of sand is very high in comparison to percentage of silt. It is observed from other plots, *i.e.*, P2, P3 and P4 that as the percentage of silt increases and percentage of sand decreases, the dynamic range in scattering coefficient with incidence angle increases.

It is mentioned earlier that quite good dynamic range with incidence angles has been observed for all plots in VV-polarization. In VV-polarization, maximum dynamic range in scattering coefficient is observed for plot 5. But, it is observed that changing the soil texture from plot 1 to plot 5, a good variation in scattering coefficient were observed. The dynamic range for VV polarization is more than the HH polarization, which infers that the polarization effect is prominent while observing the texture parameters. A quite good dynamic range of scattering coefficient has been observed for VV-pol, which infers that VV-pol may be more effective while observing the soil texture at X-band.

5.2. Regression Analysis

Regression analysis was performed to obtain best suitable incidence angle and polarization for observing the soil texture effect at X-band. Regression analysis between scattering coefficient and field values has been carried out at different incidence angle keeping moisture and roughness as constant. The confidence level was 95% and R^2 values are shown in **Table 2**. It was observed from **Table 2** that lower incidence angles show lower value of R^2 for both like polarizations whereas at higher incidence angle (*i.e.*, 70˚) both polarizations have significant value of R^2. Our earlier findings also show the similar result [16] [17]. The R^2 values for VV-pol are quite high in comparison to HH-pol which is in accordance to experimental observation. It can be said that in the bi-static measurements at X-band, VV-polarization at 70˚ incidence angle may be more suitable to observe the soil texture. Therefore, further analysis for retrieving the soil constituents has been carried out at 70˚ incidence angle and VV-polarization.

5.3. Development of Cost Function

In this step, a cost function is generated with the help of Dubois [3] model. Three parameters, percentage of sand, silt, and clay, were encoded into genes to be optimized. Vertically polarized scattering coefficient at 70˚ incidence angle is used to retrieve soil texture. The selection of polarization and incidence angle is discussed in Section 5.2.

It is observed that the scattering coefficient (σ°) can be the expressed as a function of the system parameters, incidence angle, frequency, and soil parameters, such as dielectric constant and surface roughness. The resulting expression is given in Equation (2) [2].

$$\sigma^\circ = f\left(\varepsilon, \theta, h_{rms}\right) \tag{2}$$

where, θ is the incidence angle, ε is the real part of the dielectric constant, h_{rms} is the normalized surface roughness. The dielectric constant (ε) can be expressed to the percentage of sand, silt and clay as provided in Equation (3) [24].

$$\varepsilon = \left(a_\circ + a_1 S + a_2 C\right) + \left(b_\circ + b_1 S + b_2 C\right) \times m + \left(c_\circ + c_1 S + c_2 C\right) \times m^2 \tag{3}$$

where a_i, b_i and c_i are constant and i = 1, 2 and 3. Therefore, the scattering coefficient can be expressed as give in Equation (3).

$$\sigma^\circ = f\left(m, S, Si, C, \theta, h_{rms}\right) \tag{4}$$

where m is soil moisture content, S is the percentage sand, Si is the percentage silt and C is the percentage Clay.

Table 2. R^2 values for VV and HH polarization.

Angle of Incidence (degrees)	R^2 VV Polarization	R^2 HH Polarization
30	0.03	0.03
40	0.04	0.14
50	0.24	0.15
60	0.67	0.17
70	0.76	0.46

Scattering coefficient give by Equation (4) can be used to form a cost function (Equation (5)) for the retrieval of soil constituents with Genetic Algorithm. In present case, surface roughness (h_{rms}) and soil moisture (m) are taken as constant, so we have not considered h_{rms} and m for retrieval. Cost function is provided in Equation (5).

$$C = \sum \left| \sigma_{VV}^{T}(\theta) - \sigma_{VV}^{R}(\theta) \right| \tag{5}$$

where σ_{VV}^{R} is the observed data from Scatterometer used for retrieval of the surface parameters and σ_{VV}^{T} is the Dubois model used for training as given in Equation (6).

$$\sigma_{VV}^{T} = 10^{-2.35} \frac{\cos^3\theta}{\sin\theta} 10^{0.046\varepsilon\tan\theta} \left(kh\sin^3\theta\right)^{1.1} \lambda^{0.7} \tag{6}$$

where, θ is the incidence angle, ε is the real part of the dielectric constant, kh is the normalized surface roughness and λ is the wavelength.

5.4. Retrieval of Soil Texture Constituents with Genetic Algorithm

Genetic Algorithm is applied on the cost function (Equation (5)) where theoretically calculated scattering coefficient as given in Equation (6) and observed scattering coefficient (obtained from Scatterometer) were used to compute percentage of sand, silt and clay. To compare the degree of closeness between observed, retrieved and validated sand, silt and clay, plots were drawn in **Figures 4(a)-(c)**. We observed 10 different soil texture fields (P1 to P10) form which five fields (P1 to P5) were used for development of our algorithm and rest of soil texture fields (P6 to P 10) were used to validate the algorithm. Good agreement between retrieved and observed value of soil texture, *i.e.*, percentage of sand, silt and clay were observed as shown in **Figures 4(a)-(c)**.

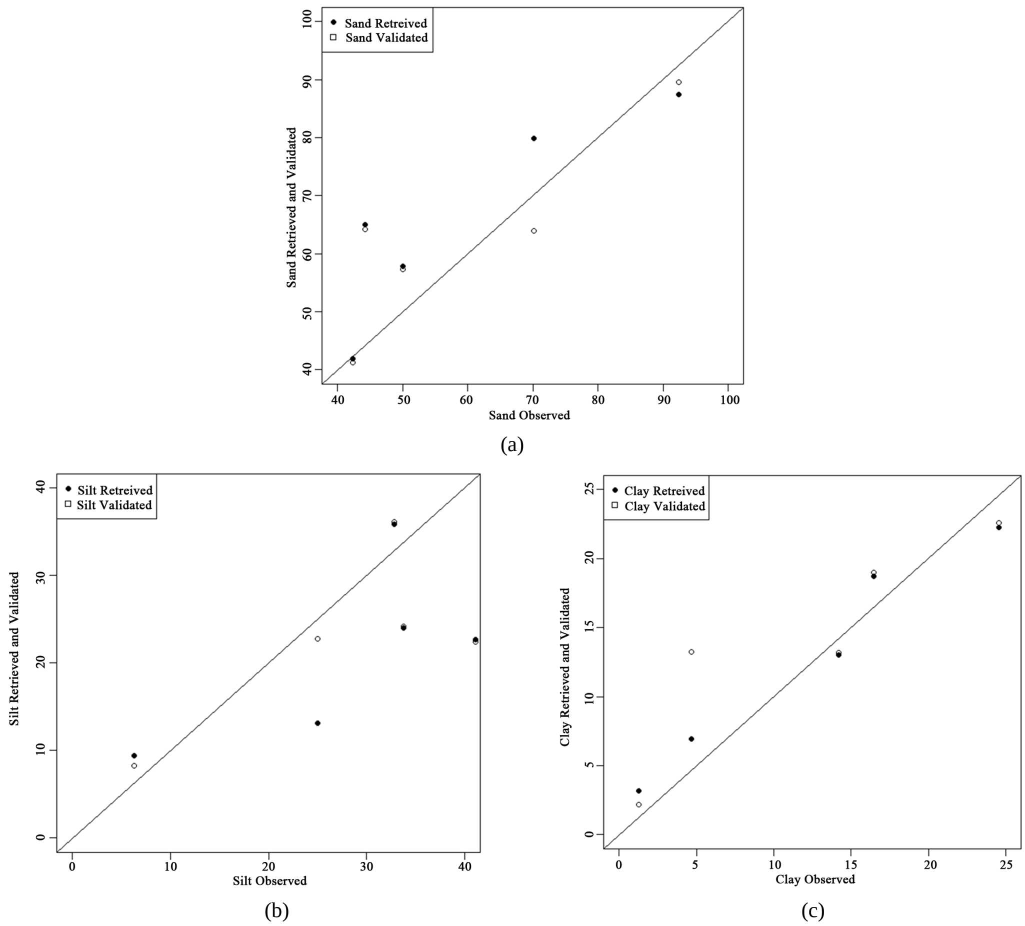

Figure 4. Plot of observed vs. retrieved and validated for ten different fields (a) for sand (b) for silt and (c) for clay.

6. Conclusion

It is observed that scattering coefficient is quite sensitive to soil texture constituents and good dynamic range in scattering coefficient at X-band was observed for the change in soil texture. The sensitivity of soil texture is better observed at higher incidence angle than lower incidence angle in both polarizations, *i.e.*, HH- and VV-pol. Change in soil texture is also sensitive for polarization and it was observed that VV-pol is more sensitive than HH-pol for different soil texture field. Retrieval of soil texture is carried out with Genetic Algorithm and it may be concluded that Genetic algorithm is one of the good optimization techniques for retrieval of soil texture constituents. A good agreement between measured and estimated values of percentage of sand, silt and clay is observed.

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