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MODEL OF MAN-MADE TARGET BENEATH FOLIAGE USING POLINSAR

B. Zou, H. Cai, L. Zhang, and M. Lin

Harbin Institute of Technology
No. 92 West Dazhi Street, Harbin 150001, China

Abstract—Polarimetric SAR Interferometry can be used for parameter inversion of ground. An appropriate model is of most importance for parameters inversion. This paper derives a series of scattering model that can be used for parameter inversion of forestry area, such as RV, RVoG, OV and OVoG. These models can reveal the characteristics of forestry area as well as establish the relationship between observed data and parameters of test area. Finally, a multi-layer random scattering model that can be used for parameter inversion of forestry area containing a man-made target is derived. An improved model is examined by the simulated data of the single-baseline polarimetric SAR interferometry. The result turns out that the improved RVoG scattering model is correct.

1. INTRODUCTION

Polarimetric SAR interferometry (PolInSAR) is not only sensitive to space distribution of vegetation and vegetation height in interferometric SAR, but also to distribution and shape of vegetation scatterers in polarimetric SAR. Hence, PolInSAR is more advantageous and precision than either polarimetric or interferometric SAR alone in extracting information of vertical vegetation structure. The coherent optimization of PolInSAR provides the optimum separation of the effective phase centers of different scattering mechanisms [1].

PolInSAR is widely regarded as a powerful tool for remote sensing application. One useful application is ground scatterer parameters inversion, especially in the forestry and vegetated areas. During the inversion process, a coherent model of the scattering process that relates the measurables to the desired physical parameters is required. In the case of vegetation area, several models, random volume (RV) scattering model, random volume over ground (RVoG) scattering model, oriented volume (OV) scattering model, and oriented volume over ground (OVoG) scattering model, have been developed [2–5]. However, these inversion models based on PolInSAR are mainly suitable for forest area, model of man-made target beneath foliage have not been studied. In this paper, a new model will be developed and analyzed, which can be used for forestry area in which more scattering centers will be considered.

For this, Section 2 introduces a generalized coherent scattering model suitable for the description of interferometric and polarimetric behavior of the vegetation area and discusses the scattering model in detail. Section 3 extends coherent scattering model suitable for the description of interferometric and polarimetric behavior of the vegetation area to the vegetation area contained man-made target. The validity of the model is demonstrated using simulated PolInSAR data in Section 4. Finally, in Section 5, some conclusions are drawn.

2. GENERALIZED COHERENCE SCATTERING MODEL

The vegetation model was derived first in [2] and extended for fully polarimetric interpretation in [3]. A generalized interferometric coherence for vegetation including random volume and oriented volume is shown in Eq. (1).

$$\tilde{\gamma} = e^{i\phi_0} \frac{\tilde{\gamma}_v(\vec{\omega}) e^{i\phi_c} + m(\vec{\omega})}{1 + m(\vec{\omega})} \tag{1}$$

where ϕ_0 and ϕ_c are the phase centers of the ground topography and tree trunk respectively; $\tilde{\gamma}_v$ and m are the complex coherence for the volume alone and object (ground or man-made target)-to-volume amplitude ratio accounting for the attenuation through the volume respectively as shown in Eqs. (2) and (3).

$$\tilde{\gamma}_v(\vec{\omega}) = \frac{I(\vec{\omega})}{I_0(\vec{\omega})}, \begin{cases} I = \int\limits_0^{h_v} e^{\frac{2\sigma(\vec{\omega})z'}{\cos\theta}} e^{ik_z z'} dz' \\ I_0 = \int\limits_0^{h_v} e^{\frac{2\sigma(\vec{\omega})z'}{\cos\theta}} dz' \end{cases} \tag{2}$$

$$m(\vec{\omega}) = \frac{2\sigma(\vec{\omega})}{\cos\theta \left(e^{2\sigma(\vec{\omega})h_v/\cos\theta} - 1\right)} \frac{\vec{\omega}^{*T} T_O \vec{\omega}}{\vec{\omega}^{*T} T_V \vec{\omega}} \tag{3}$$

where $\vec{\omega}$ is a three-component unitary complex vector defining the choice of polarization, σ the mean wave extinction in the medium and relates to polarization when vegetation layer is oriented volume, k_z the vertical wavenumber of the interferometer and θ the mean angle of incidence. T_v is the 3×3 diagonal coherency matrix for the volume scattering and T_O the object scattering coherence matrix.

The scattering model can be characterized as RV model and OV model depending on relationship between scatter center and polarization. As shown in Fig. 1, in RV model scatter has the same scattering center in different polarization; while in OV model scatter has the different scattering centers in different polarization.

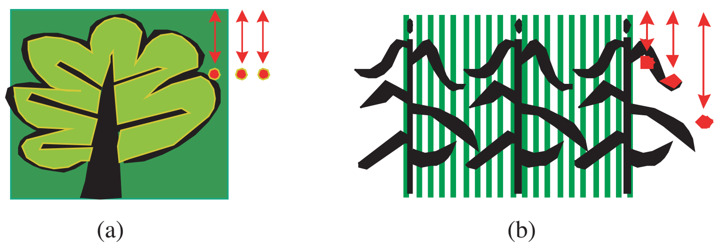


Figure 1. Scattering center of different type of vegetation in different polarization. (a) Random volume. (b) Oriented volume.

We can obtain forms of different scattering model by using different condition from Eq. (1). For example, in the case of two-layer random volume over ground, Eq. (1) is written as

$$\tilde{\gamma}_{RVoG} = e^{i\phi_0} \frac{\tilde{\gamma}_v + m(\vec{\omega})}{1 + m(\vec{\omega})} \tag{4}$$

where $\tilde{\gamma}_v$ is the complex coherence for the volume alone and independent of polarization.

3. MODEL OF MAN-MADE TARGET BENEATH RANDOM VOLUME (MTBRV)

The RVoG scattering model, which is derived in the case of natural vegetation, is not correct to the area with man-made target. In realistic scenario, man-made targets, such as houses and vehicles, can also exist in the forest area. If a man-made target is placed in the two-layer vegetation, and supposed that the size of object is comparable with resolution cell, that is, this object can be treated like a point target. When the electromagnetic wave penetrates the canopy and it is scattered, the point target is main scatter. So there is a strong scattering center in the position of the point target. In order to separate this point scatter from background clutters, a novel model is developed. Assuming the man-made target over the ground is located at z_d as shown in Fig. 2.

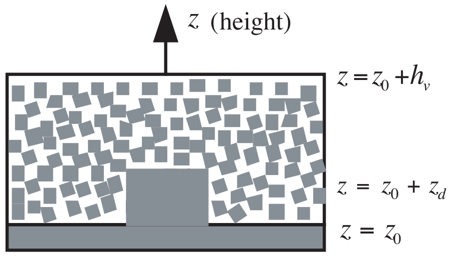


Figure 2. Schematic representation of the MTBRV model.

In the RVoG scattering model, the components related with ground scatterers are

$$\begin{aligned} I_1^G &= \int_0^{h_v} \delta\left(z'\right) e^{\frac{2\sigma z'}{\cos\theta}} T_g dz' = T_g \\ I_2^G &= T_g \end{aligned} \tag{5}$$

Because of the existing man-made target on the ground, scattering center moves to z_d from z_0, thus the component related with man-made target scatterers can be described as

$$\begin{aligned} I_1^G &= \int_0^{h_v} \delta\left(z' - z_d\right) e^{\frac{2\sigma z'}{\cos\theta}} T_g dz' = e^{\frac{2\sigma z_d}{\cos\theta}} T_g \\ I_2^G &= \int_0^{h_v} \delta\left(z' - z_d\right) e^{\frac{2\sigma z'}{\cos\theta}} e^{ik_z z'} T_g dz' = e^{ik_z z_d} I_1^G \end{aligned} \tag{6}$$

Therefore, the complex interferometric coherence of Man-made Target beneath Random Volume (MTBRV) can be derived as

$$\tilde{\gamma}_{MTBRV} = e^{i\phi_0} \frac{\tilde{\gamma}_v + e^{ik_z z_d} m\left(\vec{\omega}\right)}{1 + m\left(\vec{\omega}\right)} \tag{7}$$

Compared Eq. (4) with Eq. (7), the information of point target is related with $m(\vec{\omega})$ and $e^{ik_z z_d}$. So we can estimate the height of man-made target besides the target-to-volume amplitude ratio. The relationship between the complex interferometric coherence $\tilde{\gamma}$ and man-made target height z_d is shown in Fig. 3.

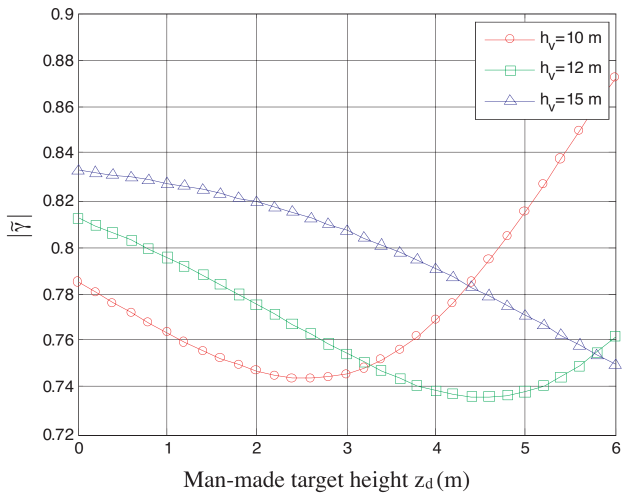


Figure 3. Coherence $\tilde{\gamma}$ variation against man-made target height in MTBRV model.

Figure 3 gives the relationship between the complex interferometric coherence and the height of man-made target in a resolution cell. When man-made target is high enough compared with the thickness of canopy, the complex interferometric coherence is mainly influenced by man-made target, thus man-made target has stronger scattering characterisitcs.

RVoG model and MTBRV model can be rewritten as the equation of a straight line in the complex plane as

$$\begin{aligned}\tilde{\gamma}_{RVoG} &= e^{i\phi_0}\left[\tilde{\gamma}_v + \mu(\vec{\omega})\left(1-\tilde{\gamma}_v\right)\right]\\ \tilde{\gamma}_{MTBRV} &= e^{i\phi_0}\left[\tilde{\gamma}_v + \mu(\vec{\omega})\left(e^{ik_z z_d}-\tilde{\gamma}_v\right)\right]\end{aligned} \tag{8}$$

where

$$0 \le \mu(\vec{\omega}) = \frac{m(\vec{\omega})}{1+m(\vec{\omega})} \le 1$$

The comparison of RVoG scattering model with MTBRV scattering model is shown in Fig. 4. Seen from Fig. 4, the volume coherence are the same in the MTBRV scattering model and RVoG scattering model, but the ground phase ϕ_0 has phase-shift because of man-made target. So far an improved RVoG scattering model has been derived.

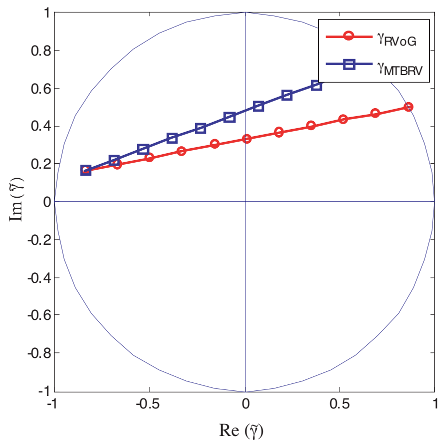
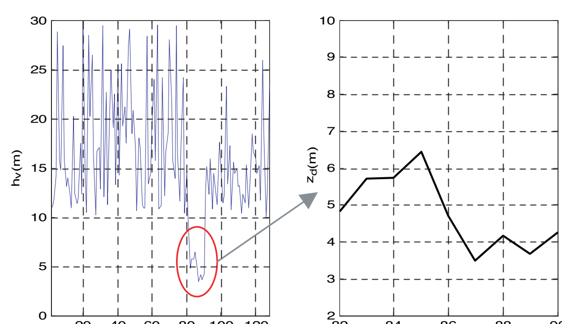


Figure 4. Coherence $\tilde{\gamma}$ variation against $m(\vec{\omega})$ in RVoG and MTBRV model.

4. EXPERIMENTAL RESULTS

A simplified three-level scattering model is used to generate the simulation data [1, 7]. The mean vegetation height is assumed 18m and the man-made target height 5 m. The ground has small slope.

Firstly, the optimized coherence coefficients are obtained by the polarimetric interferometric principle of coherence optimization (PIPCO) based on modeling data [1]. Secondly, the Treuhaft's RVoG scattering model is used in the vegetation region without man-made target and the improved RVoG model in vegetation region placed man-made target. Finally, based on the scattering model, coherence coefficients and genetic algorithms (GA) [8, 9], the extracted forest and man-made target parameters are shown in Fig. 5.



(a)

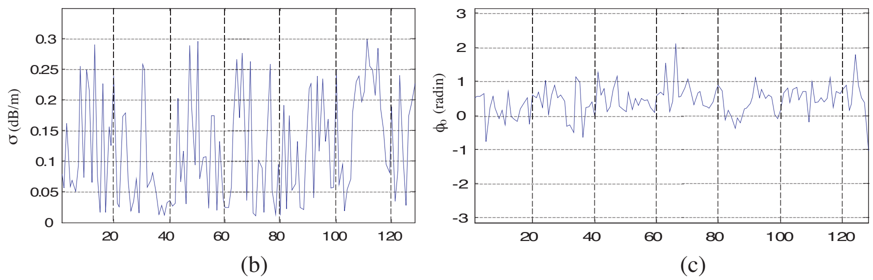


Figure 5. Inversion physical parameters of forest and man-made target. (a) Profile of the extracted forest+ man-made target height values of the 87th row. (b) Profile of the extracted mean extinction values of the 87th row. (c) Profile of the extracted ground topography values of the 87th row.

Seen from the Fig. 5(a), most of forest height ranges from 12 to 25 m, and the volume extinction coefficient ranges from 0.05 to 0.2 dB/m. In the Fig. 5(c), most of phase related to the ground topography ranges from −0.5 to 1 (in radians). Fig. 6 shows a 3-D perspective view of the estimated forest height for the whole scene. The mean forest height and man-made target height are 17.6 m and 5.5 m, respectively. In Fig. 6, only the man-made target height is shown in man-made target area beneath the forest.

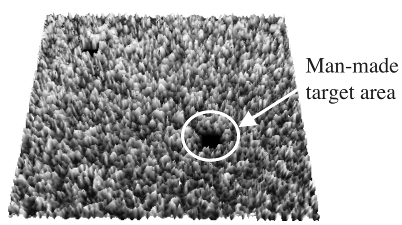


Figure 6. 3-D perspective view of the estimated forest height for the test site.

Compared modeling parameters and experimental results, the improved two-layer RVoG scattering model should be correct.

5. CONCLUSIONS

In this paper, a generalized interferometric coherence for vegetation scattering model including random volume and oriented volume is derived. Based on RVoG scattering model, an extended RVoG scattering model containing man-made target is derived. This new model is evaluated by simulated polarimetric interferometric data. Compared inversion parameter with simulation parameter, the new scattering model is correct. In the vegetation region placed man-made target, this new model can be used to extract physical parameters of man-made target beneath the vegetation.

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