Three-component Decomposition for Polarimetric SAR Images Based on Coherency Matrix

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Abstract— Original Freeman three-component decomposition was found useful in information extraction from a mix of area: city blocks, forest, ocean and land surfaces, etc.. However, it always suffers from some inconsistencies with real situation such as negative power and scattering mechanism ambiguity. It is probably because of the overestimate of volume scattering power. But intrinsically it is the inconsistency between the assumed models and the PolSAR. The deorientation method was initially found useful to alleviate this problem to some degree. However, because of the boundedness of deorientation, it is sometimes noneffective. Nonnegative eigenvalue decomposition (NNED) can absolutely solve the negative power problem. But the residual matrix except the volume scattering model is assumed equal to two. So in some sense it is under the volume scattering dominance assumption. Therefore, the decomposition should be separated into two individual parts. In this paper, for the pixels that volume scattering dominates, the NNED will be used. For the pixels that volume scattering doesn't dominate, we will start with the assumed models, and focus on developing a generalized model-based decomposition. Because for model-based scheme, we insist that one should radically start from the models and then a generalized three-component model-based decomposition is proposed, which consist of the surface, double bounce and volume scattering. Among it the generalized scattering mechanism proposed by Cloude is adopted, which provides a more accurate model for surface and dihedral scattering, and the dominant scattering component will be figured out according to the alpha angle parameter to be solved in the generalized model. Through this solution, the dominant scattering mechanism in one pixel will be preserved better. The performance of this approach is demonstrated and evaluated using the airborne AIRSAR and E-SAR data sets. The results show the advantages and improvements especially for alleviating the scattering mechanism ambiguity of oriented buildings from vegetation.

1. INTRODUCTION

Polarimetric target decomposition is found a reasonable and powerful way to analyze and interpret polarimetric SAR images, by decomposing polarimetric SAR data into several individual components representing different scattering mechanisms. There are two kinds of decompositions lying in the polarimetric decomposition theory, namely coherent and incoherent decomposition, which respectively deals with the Sinclair scattering matrix (single-look PolSAR data) and the coherency or covariance matrix (multilook PolSAR data). For many purposes and applications, a statistical averaging process for coherency matrix to reduce speckle or to compress data volume is necessary, which makes it impossible to decompose the Sinclair matrix. Therefore, the more widely used and studied decomposition technique now is the incoherent decomposition.

In Freeman decomposition, the volume model was always subtracted prior to other scattering mechanisms owing to the assumption that the HV component was only contributed by volume scattering. The nonnegative eigenvalue constraint was proved effective to limit the volume scattering power significantly. But it should be noted that the nonnegative eigenvalue method was intrinsically a coercive measure to avoid negative power, which takes the biggest one from all the values that ensure the residual matrix is still positive semi-definite, in other words, the rank of the residual coherency matrix is set equal to two. In some sense, it is based on the assumption that the volume scattering is always dominant, with the result that the surface or dihedral scattering component is partly replaced by volume scattering component, which is obviously not reasonable for all pixels. Consequently, the NNED will be employed to the pixels that volume scattering dominates. For the pixels that volume scattering doesn't dominate, we cannot use NNED anymore. Instead, we should undertake from the models themselves. Because for model-based techniques, models should be more fit with PolSAR data.

2. DEFICIENCIES DESCRIPTION AND ANALYSIS IN MODEL-BASED APPROACHES

Figure 1 shows the result of Freeman decomposition and its corresponding optical image. In Patch A are some urban buildings parallel to the radar line of sight, from which we can see that the buildings have been decomposed into red color displaying in RGB image. However, in Patch B are some buildings not parallel to radar line of sight, we can see the results display completely green color in RGB image, and that is to say, the true buildings are misinterpreted as vegetation.

Figure 1: The image on the left is from the Google Earth. The image on the right is the result of Freeman decomposition.

Yamaguchi added a helix scattering component to the original three component decomposition. Notably, the volume scattering model is also revised to better fit the real situation. By these steps, the power assigned to volume scattering is decreased, and the negative power problem and the scattering mechanism ambiguity are both spontaneously alleviated to some degree. However, because of its simplified selection criteria of volume scattering model involving the ratio of HH to VV power, the case of a dominant dihedral scattering with a small contribution from a uniformly oriented canopy may be regarded as the case that volume scattering dominates around the horizontal or vertical orientation. So we think that the selection criteria can only be applied to the pixels that volume scattering dominates. Because only under the condition that volume scattering is dominant can we utilize the total elements in coherency matrix to select a best fit volume scattering model. So in this paper, for the pixels that volume scattering dominates, the model proposed by Yamaguchi will be used for volume scattering, while for the pixels that surface or dihedral scattering dominates, the original model proposed by Freeman will be maintained.

Afterwards, the orientation angle compensation is also incorporated into model-based method, which is to minimize the last element, i.e., the cross-polarization HV component in coherency matrix. On one hand, the purpose is to decrease the value assigned to volume scattering, on other hand is to rotate the buildings or surfaces in the pixel to the direction orthogonal to the radar line of sight, i.e., the reflection symmetry condition. However, in some pixels the oriented buildings are still misinterpreted as vegetation, i.e., this idea will not work under some situations. Next we will talk about some causes.

First, let we start from the definition of deorientation,

$$R_\theta = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{pmatrix}, \quad [T(\theta)] = R_\theta [T] R_\theta^{-1} \tag{1}$$

where θ can be solved from the following equation,

$$T'_{33}(\theta) = 0 \Rightarrow 2\theta = \frac{1}{2}\tan^{-1}\left(\frac{2\mathrm{Re}(T_{23})}{T_{22} - T_{33}}\right) \tag{2}$$

it is clear that the deorientation angel 2θ ranges from $-\pi/4$ to $\pi/4$, but the orientation angel of the actual object usually ranges from $-\pi/2$ to $\pi/2$, so if the actual orientation angel is out of the deorientation angel, the deorientation is noneffective.

Secondly, the deorientation is a measure to fit the PolSAR data into the assumed surface and dihedral models by rotating the coherency matrix, however, if in one pixel there have buildings or surfaces with different orientation angles, even though the deorientation is implemented, one cannot think that the buildings are readjusted to the direction orthogonal to radar line of sight as the models predict, under this condition the deorientation will also be noneffective.

3. PROPOSED DECOMPOSITION

3.1. Generalized Scattering Mechanism

The generalized scattering mechanism takes the normalized form of its corresponding Pauli-vector,

$$\underline{u} = \left[\cos\delta \;\; \sin\delta\cos\omega e^{j\phi} \;\; \sin\delta\sin\omega e^{j\varphi}\right]^T \tag{3}$$

The coherency matrix of generalized scattering mechanism can be described as follows,

$$[T_g] = \begin{pmatrix} \cos^2\delta & \cos\delta\sin\delta\cos\omega e^{-j\phi} & \cos\delta\sin\delta\sin\omega e^{-j\varphi} \\ \cos\delta\sin\delta\cos\omega e^{j\phi} & \sin^2\delta\cos^2\omega & \sin^2\delta\cos\omega\sin\omega e^{j(\phi-\varphi)} \\ \cos\delta\sin\delta\sin\omega e^{j\varphi} & \sin^2\delta\cos\omega\sin\omega e^{j(\varphi-\phi)} & \sin^2\delta\sin^2\omega \end{pmatrix} \tag{4}$$

where δ, ω, ϕ, φ are unknown real angles, together with the power coefficient, there have a total of 5 free variables. It is clearly shown that generalized scattering mechanism takes the possible HV cross-polarization component contributed by surface or dihedral scattering into consideration.

3.2. Decomposition Framework

As mentioned above, for the pixels that volume scattering dominates, the general NNED will be used, while for the pixels that volume scattering is not dominant, we use the decomposition framework as follows,

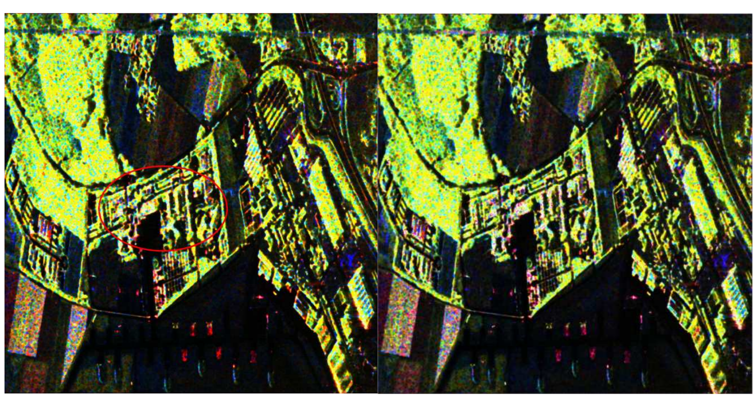
$$\langle[T]\rangle = fT_g + f_s\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} + f_d\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} + f_v\begin{bmatrix} 0.5 & 0 & 0 \\ 0 & 0.25 & 0 \\ 0 & 0 & 0.25 \end{bmatrix} \tag{5}$$

in which we adopt the model proposed by Freeman for the volume scattering. Because we insist that the volume scattering is strongly depolarized and has the biggish entropy. It should be noted that this decomposition also takes the situation that there have buildings or surfaces with two different orientation angles into consideration.

Once the coefficients are solved, the alpha angle will be used to identify the dominant scattering mechanism in one pixel, when applied to the proposed decomposition, it is equivalent to the following expression,

$$k = \frac{T(1,1)}{T(2,2)+T(3,3)} = \frac{\cos^2\delta}{\sin^2\delta} \tag{6}$$

So, if $k \leq 1$, $P_s = f + f_s$, $P_d = f_d$, $P_v = f_v$, if $k \geq 1$, $P_d = f + f_d$, $P_s = f_s$, $P_v = f_v$.



(a) (b)

Figure 2: (a) General NNED. (b) The proposed.

4. EXPERIMENTS AND RESULTS

The E-SAR Oberpfaffenhofen polarimetric data are used to test the performance of this approach. The result of the proposed decomposition is shown in Figure 2. The general NNED are also carried out for comparison study.

Figure 2(a) shows the result of general NNED, Figure 2(b) shows the result of the proposed method. Let us see the area in the elliptic region, in which are some buildings in urban areas, from which we can clearly see that more pixels have been decomposed into dihedral scattering objects displaying in red color. This indicates that the true scattering mechanism has been preserved better by the proposed method such as surface dihedral scattering from the oriented buildings and the result is more consistent with the actual situation.

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