Detection of the Coherent Scatterers using Sub-Aperture Polarimetric SAR data: the Preliminary Results

Hong Zhang(1), Xi Chen(1)(2), Chao Wang (1)

(1) China Remote Sensing Satellite Ground StationChinese Academy of Sciences

Beijing 100086, China, hzhang@rsgs.ac.cn

(2)State Key Laboratory of Remote Sensing Science, Jointly Sponsored by the Institute of Remote Sensing Applications of Chinese Academy of Sciences and Beijing Normal University Graduate University of the Chinese Academy of Sciences Beijing 100101, China

Abstract

The objective of this paper is to assess the sub-aperture analysis technique for the detection of coherent scatterers (CSs) using polarimetric SAR data. The non normalized coherence is used to greatly improve the contrast between the clutter and the target, since it can preserve the strong intensity information of the target. Furthermore, by applying a way similar to the polarimetric interferometry coherence optimization, the optimal coherence can be achieved by tuning the polarization states using the full polarimetric SAR data. Finally, utilizing the ALOS PALSAR data, the preliminary results and analyses of the detection of CSs are demonstrated.

Keywords: Polarimetric SAR, Sub-Aperture, Coherent Scatterer

1. INTRODUCTION

The coherent scatters (CSs) often have a trihedral or dihedral scattering behavior and appear the deterministic targets with a strong intensity. A similar target is referred as Persistent Scatterers (PSs) in SAR Interfermetry[1], the selection of this kind of scatterers is based on the temporal amplitude stability and work when a large amount of long time series data is available. However, a majority of PSs are often found in urban area and seldom in natural area.

Usually, the sub-aperture analysis includes the following steps: compensation of Doppler shift and un-weighting in azimuth or range direction, spectrum division in sub-apertures, zero-padding, hamming weighting of each sub-apertures and computation of the correlation between the sub-apertures. Recently, using this method, the normalized correlation coefficient and entropy between the sub-aperture SAR images in a certain polarization channel were obtained for analyzing the anisotropic and stationary characteristic of the scatterers in the imaging scene[2-4]. The sub-aperture analysis shows the potential of the detection of CSs.

Moreover, as we know, the number of PSs greatly affects the estimation accuracy for subsidence velocity or ground surface deformation in PSInSAR applications, the detected CSs can be considered as additional PSs in suburban area or natural area.

2. SUB-APERTURE POLARIMETRIC ANALYSIS

The sub-aperture normalized coherence are often used to evaluate the phase similarity between two sub-aperture images and computed according to

$$\gamma_{nor} = \frac{|\langle x_1 x_2^* \rangle|}{\sqrt{\langle x_1 x_1^* \rangle \langle x_2 x_2^* \rangle}} \quad (1)$$

Where, x_1 and x_2 are the complex values associated with sub-aperture image X_1 and X_2 for a given pixel. When the image spectrum is completely different in one direction, γ is expected to be zero over the developed speckle. However, the use of γ was found to be quite disappointing for target detection. The main reason is that the normalization of γ (through the denominator) does not permit to consider intensity information in the detection aspect. Thus, the non normalized parameter is introduced to capture both intensity and phase information of targets

$$\gamma = |\langle x_1 x_2^* \rangle| \quad (2)$$

Because the point target may present a nonstationary behavior throughout the entire illumination time, which makes this target visible only on a sub-spectrum in the azimuth/range direction. The polarimetric information is utilized to provide additional information for target analysis and improve the detection of the CSs.

Similar to the approach for optimizing the polarimetric interferometry coherence in [6], we define two target vector k_1 and k_2 corresponding to the two sub-aperture images respectively, ω_1 and ω_2 indicate two scattering mechanisms, so the non normalized coherence projected on the arbitrary scattering mechanisms is defined

$$\gamma_{pol} = \omega_1^{*T} [\Omega_{12}] \omega_2 \quad (3)$$

where $[\Omega_{12}] = \langle k_1 k_2^{*T} \rangle$.

So, the Lagrange multipliers λ_1 and λ_2 are introduced to achieve the maximum value of γ_{pol}.

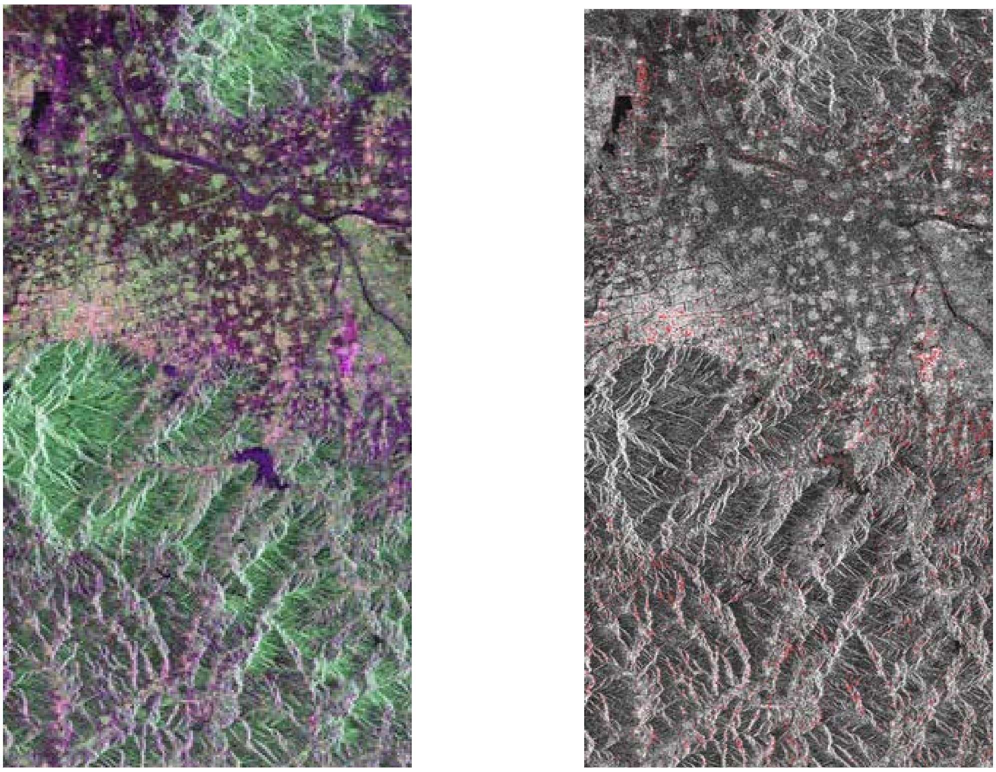
$$L = \omega_1^{*T}[\Omega_{12}]\omega_2 + \lambda_1(\omega_1^{*T}\omega_1 - 1) + \lambda_2(\omega_2^{*T}\omega_2 - 1) \quad (4)$$

We can solve this maximization problem by setting the partial derivatives to zero,

$$\begin{cases} [\Omega_{12}][\Omega_{12}]^{*T}\omega_1 = v\omega_1 \\ [\Omega_{12}]^{*T}[\Omega_{12}]\omega_2 = v\omega_2 \\ v = 4\lambda_1\lambda_2^* \end{cases} \quad (5)$$

And then, some specific algebraic analyses assure the maximum value of non normalized coherence [5]

$$\gamma_{pol}^{\max} = \sqrt{v_{\max}} \quad (6)$$



(a) (b)

Figure1. (a)Pauli Decomposition Image of ALOS PALSAR polarimetric data (b)Detected coherent scatterers(in red) superimposed on the HH image

3. DETECTION OF COHERENT SCATTERERS

The ALOS PALSAR L-band polarimetric SAR data is used to validate the sub-aperture polarimetric analysis for the detection of CSs. The Pauli decomposition image of the study area is shown in Figure1. Since the CSs are defined as scatterers that exhibit a highly correlated behavior over the sub-apertures, strong and stable scatterers, such as corner reflectors or man-made targets, show a high coherence. The well-oriented buildings are typical examples. So the urban area is expected to include a lot of CSs with a trihedral or dihedral scattering behavior, in contrast, the natural areas with a random scattering behavior should have a low coherence and less polarization dependence. However, when the SAR image contains man-made targets, it is required to incorporate the dependence of target responses on the squint angle and frequency. To avoid the effect of the spectral decorrelation in azimuth direction induced by the response integration along a wide azimuth angle, sub-aperture decomposition is performed to detect the CSs in the range direction only.

Although the maximum optimal coherence image gives the best contrast between the CSs and the surrounding clutter, the layover in SAR image due to the presence of steep terrain slopes or low incident anlge appears as bright feature, which may make a false detection of CSs. To avoid this problem, a new parameter γ_e is computed to detect the real CSs with the three optimal coherences

$$\gamma_e = \frac{\gamma_{pol}^{opt1}}{\sum_{i=1}^{3}\gamma_{pol}^{opti}} \quad (opt1>opt2>opt3)$$

And then, the detection of CSs can be accomplished by setting a suitable threshold for the new coherence map γ_e. Because the targets from the volume random scattering have a equal backscattering response at all possible combination of the polarization states, the parameter γ_e

not only utilizes the capability of the maximum optimal coherent for detecting CSs, but also reduce the false detected CSs due to the effect of layover on the dense vegetation area in the top and middle of image. When the threshold of 0.95 for γ_e have been used, the detected CSs(in red) superimposed on the HH image are shown in Figure.1(b).

4. PROPERTIES OF COHERENT SCATTERERS

For the sake of the performance comparisons, the sub-aperture analysis is also applied to the single polarized SAR data (HH, HV and VV). The number of the detected CSs using single-polarized SAR data and polarimetric data are expected to be different. The histogram of the number of the detected CSs versus the threshold for the non-normalized coherence γ is shown in figure2. When only the single polarized SAR data is used, the most CSs are detected with the HH data and few CSs are detected with the HV data. Since HV polarization implies a depolarization phenomenon of a given target and CSs are usually deterministic scatterers, a poor detection performance in HV image is not surprising. However, the number of the detected CSs increases greatly with the maximum optimal coherence, when the polarimetric data have been used.

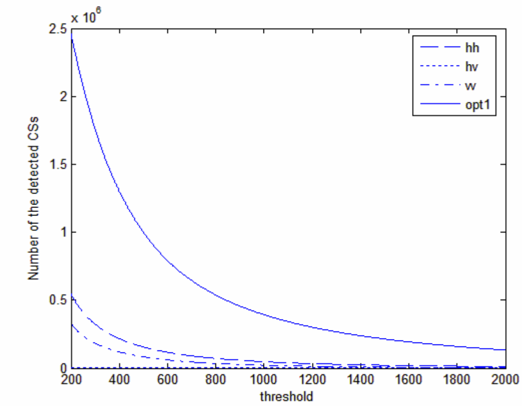


Figure2. The number of the detected CSs versus the threshold

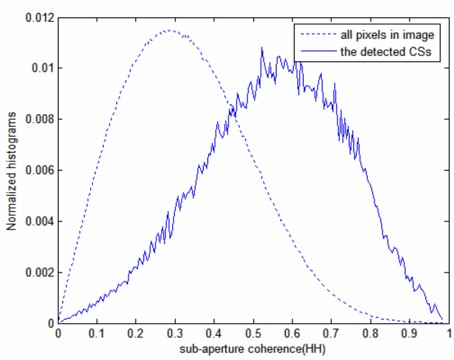


Figure3. The normalized histograms of sub-aperture coherence

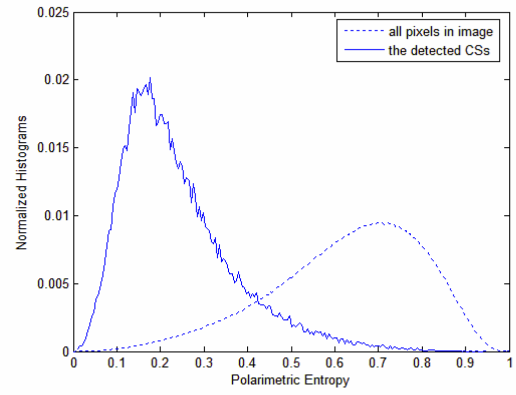


Figure4. The normalized histograms of polarimetric entropy

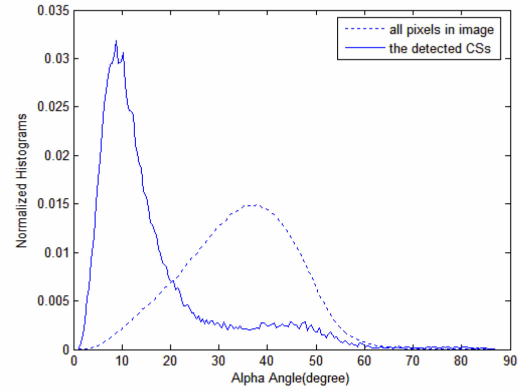


Figure5. The normalized histograms of alpha angle

Then, the sub-aperture coherence and polarimetric properties of the detected CSs are also evaluated in this section. The normalized histograms of the sub-aperture normalized coherence in the HH image given in Figure3 show a low normalized coherence of about 0.3 due to the existence of a lot of natural areas, but the detected CSs give a higher mean coherence of about 0.6. We also can see that the normalized coherence don't have very high coherence for the detection of the CSs.

As for the polarimetric properties, the definition and meanings of the polarimetric entropy and alpha angle can be found in [7]. The polarimetric entropy indicates the randomness of a scattering medium from isotropic scattering (H=0) to totally random scattering (H=1). Seen from figure4, it is obvious that the detected CSs show a deterministic scattering behavior with a lower polarimetric entropy. Finally, Figure.5 shows the histogram of the alpha angle representing the averaged scattering mechanism from trihedral scattering to double bounce scattering for the entire image and the detected CSs. The majority of detected

CSs is characterized as trihedral ($0^\circ \leq \alpha \leq 20^\circ$) scatterers, some are dipole-like ($40^\circ \leq \alpha \leq 50^\circ$) scatterers.

5. CONCLUSIONS

CSs are deterministic scatterers not being affected by speckle. In this sense, the corresponding characteristic of the phase is also deterministic and reflects to a frequency independent spectral behavior in the spectral domain. The ALOS PALSAR L-band polarimetric SAR data is applied to present the preliminary results of the detection of CSs using sub-aperture analysis. When the only single polarized SARdata are applied to the sub-aperture analysis, the HH image gives the best performance for the detection of CSs. Since the behavior of the CSs in the HV image is not apparent, the HV image is not suitable to detect the CSs. Once the polarimetric SAR data are available for sub-aperture analysis, the coherence γ_e is attained for maximizing the contrast of the given target and the surrounding clutter and can reduces the number of the false detected CSs due to the effect of layover on the dense vegetation area.

This sub-aperture analysis method proposed in this paper is expected to provide the additional PSs in the suburban areas or natural areas for improving the estimation accuracy of the PSInSAR applications. And other potential applications also include military target detection, moving target analysis, etc.

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