POLARIMETRIC SCATTERING ANALYSIS FOR ACCURATE OBSERVATION OF STRICKEN MAN-MADE TARGETS USING A ROTATED COHERENCY MATRIX

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1. INTRODUCTION

M7 class big earthquakes successively struck in Japan for last few years. Since the earthquakes accompanied subsequent aftershocks including M5-6 class events, terrible secondary disasters were often occurred. They were mainly caused by houses collapses, large scale landslides, and so forth. To escape damages from such secondary disasters, it is very important to grasp the state of the disaster areas, especially near the residential (man-made targets) areas. However, it is sometimes difficult to carry out on-site inspections for precisely grasping the situation in the aftermath of the disasters. Under such emergent situation, radar remote sensing using fully or quad. polarimetric information [1, 2, 3, 4, 5] is an efficient solution, since it can powerfully work even under bad weather condition, and day or night.

The scattering power decomposition [6, 7], which makes full use of quad. polarimetric SAR data, may be one of the most powerful tools for observing disaster areas. According to the decomposition procedure, the total received power can be decomposed into the fundamental physical models as double-bounce scattering P_d, surface scattering P_s, volume scattering P_v, and helix scattering P_c. So, by appropriately evaluating each decomposed scattering component, one may detect the stricken residential areas. Man-made target detection can be carried out by extracting the double-bounce scattering contribution P_d, since P_d is mainly generated from fine dihedral structure between vertical wall of building and ground surface. However, it is sometimes difficult to distinguish the man-made targets from other natural distributed ones, since polarimetric feature of P_d is strongly dependent on the orientation of their alignment and the inclination of the surrounding ground. So, a useful marker P_d may no longer be observed when 1) the radar illumination is not normal to the alignment of the man-made targets (mainly in urban areas), and/or 2) ground surface around the man-made targets is strongly inclined (mainly in mountainous areas). Hence, the accuracy improvement of the scattering power decomposition is eagerly required.

In this paper, to improve the accuracy of the man-made target detection, we present a simple modification of the scattering power decomposition method by introducing *a polarimetric rotation concept* [8, 9, 10]. As shown in Fig.1, by carrying out the unitary rotation procedure to the coherency matrix, the original POLSAR image data set is able to be polarimetrically rotated around the radar line-of-sight. So one can obtain the modified coherency matrix, which may have pseudo-normal alignment direction to the radar illumination. After the rotation procedure, the four-component decomposition is carried out to the modified matrix. Consequently, the polarimetric marker P_d can be emphasized and easily extracted even from obliquely oriented and/or inclined man-made targets.

Furthermore, to make the dependency of the polarimetric rotation feature on the incident angle, we carry out polarimetric scattering analysis for simplified man-made targets model, which consists of finite number of rectangular parallelepiped dielectric objects on ground plane. Here, we utilize the Finite-Difference Time-Domain (FDTD) method in the analysis.

2. SCATTERING POWER DECOMPOSITION USING A ROTATED COHERENCY MATRIX

First, we shall briefly show the scattering power decomposition for the average coherency matrix $\langle [T] \rangle$ acquired by fully or quad. POLSAR sensor. By using the four-component scattering model [6, 7], the measured matrix $\langle [T] \rangle$ can be expanded into

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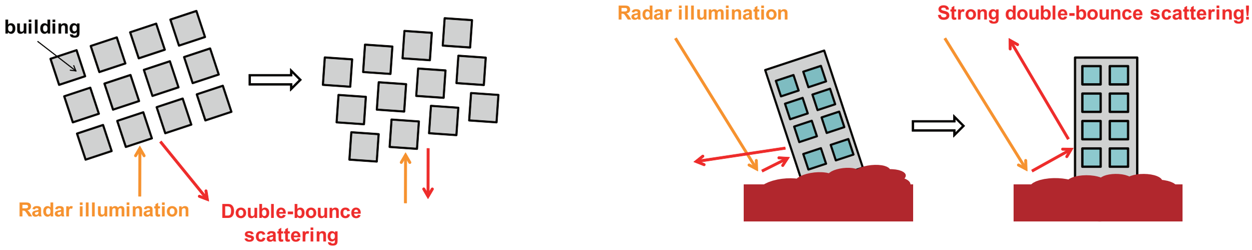


(a) Small incident angle case (b) Large incident angle case

Fig. 1. Polarimetric rotation.

physically based model as double-bounce scattering, surface scattering, volume scattering, and helix scattering, *i.e.*

$$\langle [T] \rangle = f_d [T]_{double} + f_s [T]_{surface} + f_v \langle [T] \rangle_{vol} + f_c \langle [T] \rangle_{helix}. \tag{1}$$

By determining the unknown expansion coefficients f_d, f_s, f_v and f_c, the total scattered power P_t can be decomposed into each scattering component, P_d, P_s, P_v and P_c.

The three scattering components P_d, P_s, P_v is assumed under the reflection symmetry condition [6]. Hence, the (1,3), (2,3) and (3,1), (3,2) elements in the expanded coherency matrices are always zero. Whereas, the helix scattering component P_c introduced in Refs.[7] has rotational symmetry feature around radar line-of-sight. So the (1,2), (1,3) and (2,1), (3,1) elements in the helix scattering matrix become zero. Taking into account the fact, it is found that the (1,3) and (3,1) elements of the acquired matrix $\langle [T] \rangle$, T_{13} and T_{31}, are not utilized at all in the procedure of the four-component scattering power decomposition. It is, therefore, expected that by making full use of T_{13} or T_{31}, one can improve the accuracy of the scattering power decomposition.

We shall now introduce the "*rotation*" scheme to the polarimetric matrix before doing the power decomposition procedure, to improve the precision of the target classification. If quad. polarimetric SAR data are acquired by actual POLSAR system, the original data set may be polarimetrically rotated around the radar line-of-sight, as depicted in Fig.1. So, by rotating the original data sets with appropriate rotation angle θ:

$$\langle [T'] \rangle = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & -\sin 2\theta \\ 0 & \sin 2\theta & \cos 2\theta \end{bmatrix} \langle [T] \rangle \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix} \tag{2}$$

we then obtain the modified image with pseudo normal alignment direction. Here, we determine the appropriate rotation angle θ by reducing the un-utilized element to be zero [9, 10], *i.e.*

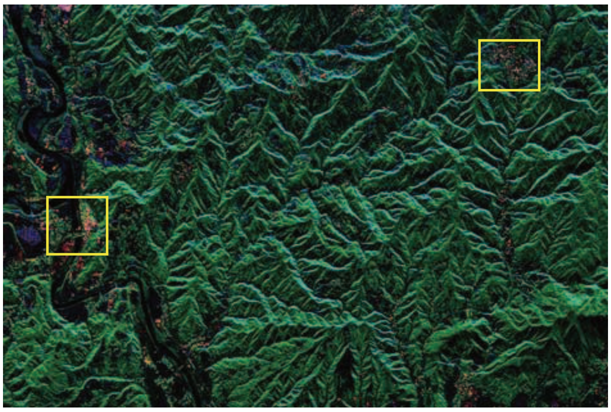
$$T'_{13} = T_{12} \sin 2\theta + T_{13} \cos 2\theta \sim 0. \tag{3}$$

After the rotation procedure, we carry out the four-component decomposition using the rotated data set. It is expected by doing this rotation procedure that the useful polarimetric marker P_d is emphasized and easily extracted even from obliquely oriented and/or strongly inclined man-made targets.

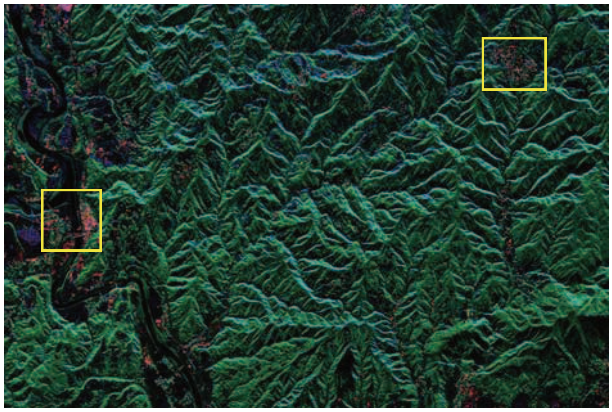
3. POLSAR IMAGE ANALYSIS

The scattering power decomposition with the proposed polarimetric rotation is carried out to the quad-pol. SAR data acquired by Pi-SAR, which is an airborne polarimetric SAR system developed by NiCT and JAXA, Japan.

Figure 2 shows the decomposed result around Yamakoshi village, Japan, which was stricken by the Mid-Niigata Prefecture Earthquake (M6.8) on Oct. 23, 2004. The data sets utilized here was acquired on Nov. 4, 2004. In the figure, each decomposed power is color-coded as follows. 1) Red is painted for double-bounce scattering P_d, 2) Blue is for surface scattering P_s, and 3) Green is for volume scattering P_v. Fig.2(a) depicts the result without the rotation procedure, and Fig.2(b) is that with the rotation. It is found from Fig.2(a) that one can see the bright green color due to volume scattering P_v not only in the natural target areas but also in the residential areas. It may be due to the fact that the complex multiple scattering in the man-made targets environment occur and make non-reflection and/or non-rotation symmetry condition. Resultantly, the man-made buildings are partially regarded as volume scattering targets. On the other hand, one cannot observe such fatal misclassification in Fig.2(b). The obliquely oriented man-made targets on inclined ground plane is precisely considered as double-bounce scattering targets. This means that by introducing the proposed polarimetric rotation consept, the accuracy of the man-made target detection is improved for both obliquely oriented and/or inclined residential houses.



(a) RGB color composite image ”before rotation”



(b) RGB color composite image ”after rotation”

Fig. 2. Result of POLSAR image analysis in a stricken region (Yamakoshi village, Nov.4, 2004).

4. FDTD POLARIMETRIC SCATTERING ANALYSIS

Finally, in order to confirm the validity of the proposed method, we carry out polarimetric scattering analysis for simplified man-made targets model. As shown in Fig.3, the model consists of finite number of rectangular parallelepiped dielectric objects on ground plane. The Finite-Difference Time-Domain (FDTD) method is here utilized in the analysis.

In the presentation, to make the dependency of the polarimetric rotation feature on the incident angle clear, we will present the FDTD results for both small and large incident angle cases.

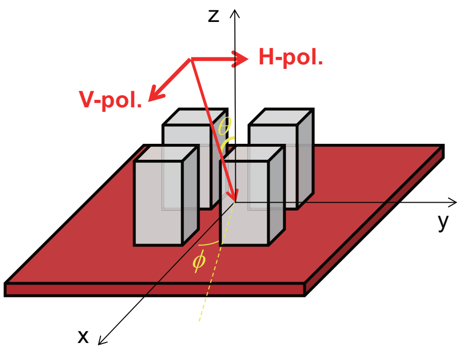


Fig. 3. Geometry of the problem (Simple man-made targets model).

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