FOUR-COMPONENT SCATTERING POWER DECOMPOSITION WITH ROTATION OF COHERENCY MATRIX

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1. INTRODUCTION

The four-component decomposition scheme [1] decompose polarimetric data of imaging pixel area into surface scattering, double bounce scattering, volume scattering, and helix scattering components. It is known that oriented urban area and vegetation signatures have similar polarimetric responses and are decomposed into the same volume scattering mechanism in the decomposition. Man-made structures orthogonal to radar direction of illumination are decomposed into double bounce objects exhibiting "red" in the decomposed image. However, the oriented urban building blocks and houses with respect to radar illumination are decomposed into volume scattering objects exhibiting "green". Since "*green*" color is allotted for volume scattering, one may confuse the area as vegetation caused by volume scattering. Although they have strong backscattering power compared to those of vegetation, they are classified as "green" in case the RGB color-coding is used. It is desirable to classify obliquely oriented urban blocks/buildings as man-made structure (*red*) from the classification point of view. In this paper, a new decomposition scheme of first using a rotation of the coherency matrix followed by the four-component decomposition is presented. It is shown using airborne Pi-SAR data sets that oriented urban areas are clearly distinguished from volume scattering as double bounce objects by the rotation of coherency matrix.

2. ROTATION OF COHERENCY MATRIX AND FOUR-COMPONENT DECOMPOSITION

In order to resolve this oriented urban problem, we propose a new decomposition method using an idea of deysing (see Fig. 1) first conceived by Huynen [2]. If quad-pol data are acquired by the actual POLSAR system, the image may be rotated around the radar line of sight. By rotation of the image (or equivalently data sets), we can obtain rectified images. We adopt this concept and apply it for the four-component decomposition [1].

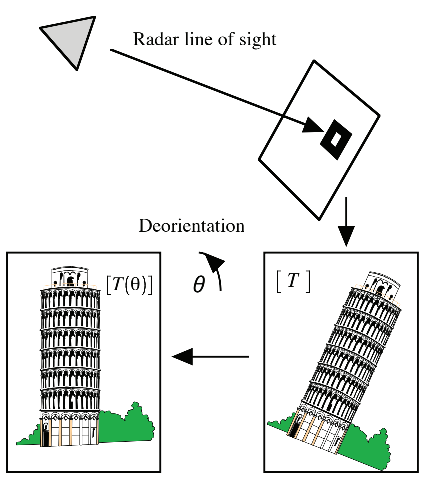


Fig. 1 Rotation of pol. image

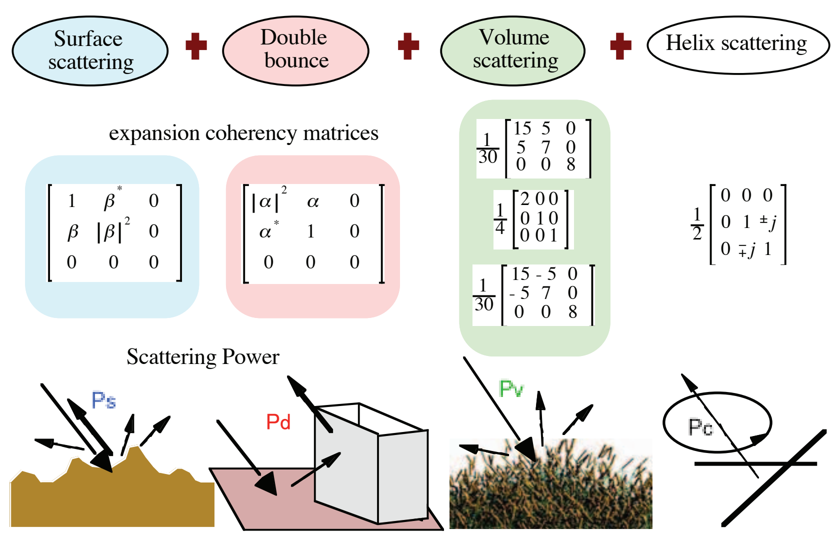


Fig. 2 The four-component decomposition of scattering powers Ps, Pd, Pv, and Pc

2.1. Rotation of Coherency Matrix

Assume the measured coherency matrix as

$$[T] = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix} \tag{1}$$

Then the coherency matrix after rotation by angle θ can be obtained by

$$\left[T(\theta) \right] = \left[R_P(\theta) \right] \left[T \right] \left[R_P(\theta) \right]^{\dagger} \tag{2}$$

$$\left[R_p(\theta) \right] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix} : \text{rotation matrix} \tag{3}$$

We denote the elements of the rotated coherency matrix as

$$[T(\theta)] = \begin{bmatrix} T_{11}(\theta) & T_{12}(\theta) & T_{13}(\theta) \\ T_{21}(\theta) & T_{22}(\theta) & T_{23}(\theta) \\ T_{31}(\theta) & T_{32}(\theta) & T_{33}(\theta) \end{bmatrix} \tag{4}$$

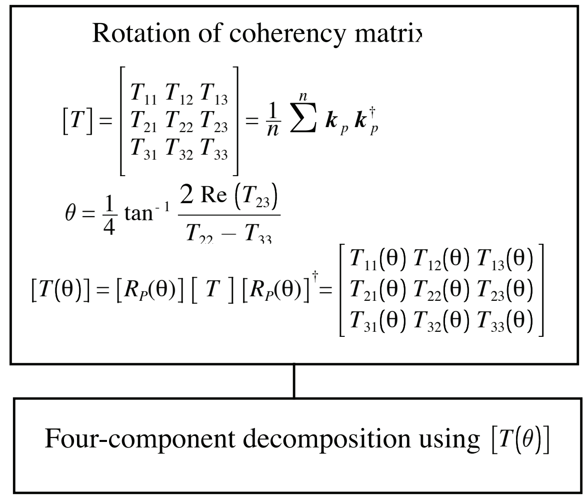


Fig. 3 Four-component scattering power decomposition using rotated coherency matrix

2.2. Minimization of T33

Since T33 component consists only of the cross polarized term, we adopt the idea of minimizing it. T33 term in (2) can be written as

$$T_{33}(\theta) = T_{33} \cos^2 2\theta - \text{Re}\left(T_{23}\right) \sin 4\theta + T_{22} \sin^2 2\theta \tag{9}$$

The derivative with respect to θ is given by

$$T_{33}^{'}(\theta) = 2\left(T_{22} - T_{33}\right) \sin 4\theta - 4 \,\text{Re}\left(T_{23}\right) \cos 4\theta \tag{10}$$

Therefore, the rotation angle can be derived from $T_{13}(\theta) = 0$, yielding

$$\tan 4\theta = \frac{2\,\text{Re}\left(T_{23}\right)}{T_{22} - T_{33}} = \frac{4\,\text{Re}\left\langle c^{*}\left(a-b\right)\right\rangle}{\left\langle \left| a-b \right|^2 \right\rangle - 4\left\langle \left| c \right|^2 \right\rangle} \tag{11}$$

$$\theta = \frac{1}{4} \tan^{-1}\left(\frac{2\,\text{Re}\left(T_{23}\right)}{T_{22} - T_{33}}\right), \qquad -\frac{\pi}{4} < \theta < \frac{\pi}{4} \tag{12}$$

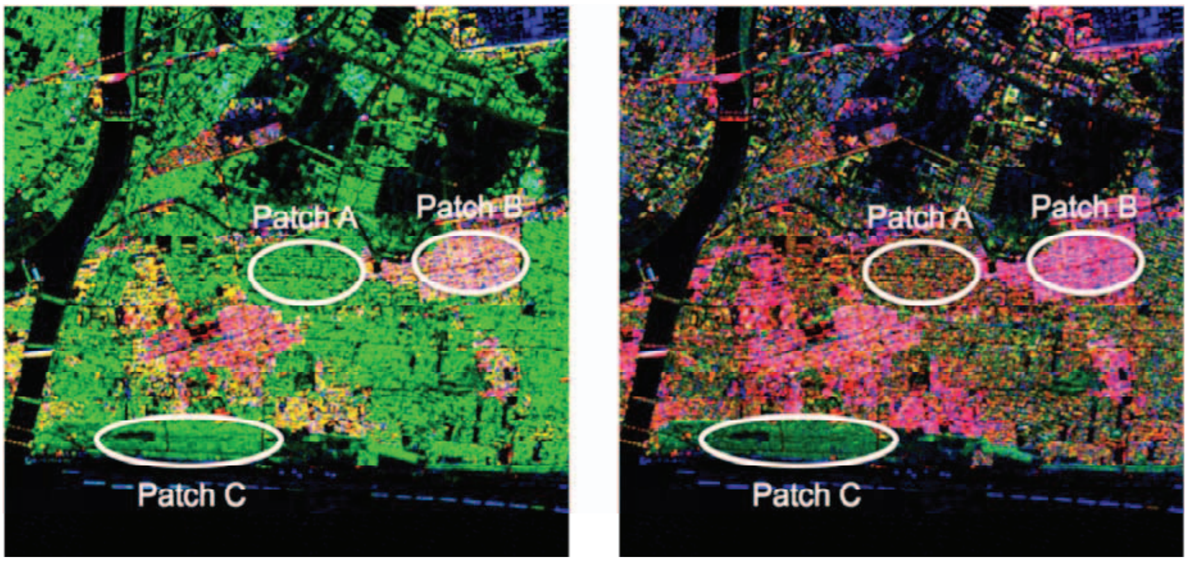
The expression (12) is of the same form as the phase of the correlation coefficient in the circular polarization basis [3]-[6], which is also used for surface slope estimation [5].

2.3 Four-component Decomposition with Rotated Coherency Matrix

A rotated coherency matrix can be created using (12) and (2). We apply the four-component decomposition to this rotated matrix. The schematic decomposition algorithm is shown in Fig. 3, in which all terms are directly derivable from the coherency matrix elements.

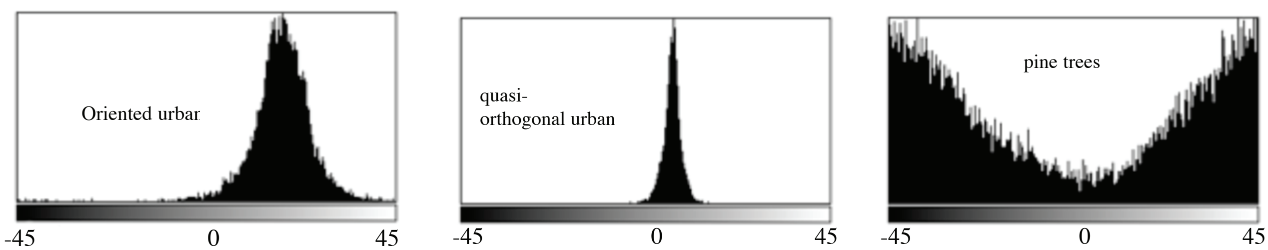
3. DECOMPOSITION RESULTS

Fig. 4 shows decomposed imagery of Niigata, Japan, before and after rotation of the coherency matrix for the sake of comparison. The quad-pol data set used is L-band Pi-SAR data acquired over Niigata, Japan, in 2004. The resolution on the ground is 3 by 3 meters. The area contains heterogeneous objects such as oriented urban buildings in certain directions, rivers, bridges, pine trees, etc. Most of "green" areas in urban in (a) are decomposed into red or pink in the image (b).



(a) Original decomposition　　　　(b) Decomposition after rotation

(Green: volume scattering power *Pv*, Red: double bounce scattering power *Pd*, Blue: surface scattering power *Ps*)

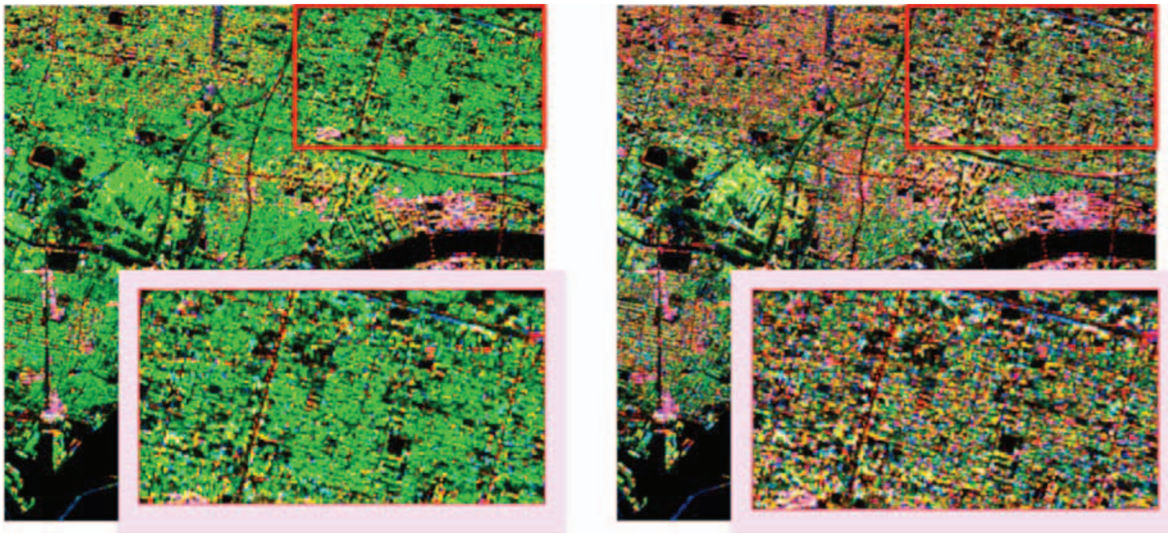


(c) Patch A　　　　(d) Patch B　　　　(e) Patch C

Fig. 4 Decomposed imagery and angular distribution of Niigata, Japan, by L-band Pi-SAR quad. pol data sets

In order to examine quantitatively, the rotation angle distributions of selected patches in Fig. 4 (a) are shown in (c)-(e). The angle distribution of patch A in (c) is concentrated around 25 degrees for oriented "*green*" urban area in (a). The angle distribution of patch B of "*orthogonal urban*", yields the peak at 5 degrees in (d) which is consistent with the actual situation, whereas the angle is distributed rather randomly (e) for patch C in the pine forest area.

Other polarimetric data set of downtown Niigata area is also decomposed to show the effectiveness of this method. Fig. 5 shows the comparison of the decomposition before and after the rotation, which is self-explanatory.



(a) before rotation (b) after rotation

Fig. 5 Four-component scattering power decomposition of downtown Niigata, Japan, before and after T33 rotation.

4. CONCLUSION

This paper presented a new decomposition scheme implementing a rotation of the coherency matrix before carrying out the four-component decomposition. By minimizing the cross-polarized component, the rotation angle is retrieved. Using the recovered angle the coherency matrix is rotated. The decomposition algorithm is based on the coherency matrix elements only. This method is quite simple and effective. It is successfully carried out to quad. pol. SAR (Pi-SAR) data sets and discriminated oriented urban blocks and vegetation as different scattering objects which previously were difficult to be discriminate. Arbitrarily oriented urban areas are then correctly classified into double bounce man-made structures. In addition, the image quality increased compared with the original decomposition within the fixed specification frame of radar resolution.

Acknowledgment

The authors are grateful to JAXA for providing L-band Pi-SAR Quad Pol data sets.

5. REFERENCES

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