A New Four-component Scattering Power Decomposition Applied to ALOS-PALSAR PLR Data Sets

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Abstract

A new four-component scattering power decomposition using a rotation of the coherency matrix is presented in order to distinguish vegetation and oriented urban area with respect to the direction of radar illumination in the volume scattering mechanism. 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. 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 ALOS-PALSAR data sets that oriented urban areas are clearly distinguished from volume scattering as double bounce objects by the rotation of coherency matrix.

I. Introduction

There are various image analysis methods for quad-pol. data sets [1, 2]. The representative and fundamental methods are based on ensemble averaging of several pixels bearing the second order statistics of polarimetric information:

- The HV basis imaging
- The Pauli basis imaging
- H-Alpha-Anisotropy imaging
- Power decomposition imaging

The most frequently used method is the H-Alpha-Anisotropy developed by Cloude and Pottier [1]-[4] based on the eigenvalues of coherency matrix. The second one is the scattering power decomposition method [5]-[7] based on physical scattering models, which was first developed by A. Freeman and S. Durden [5]. This paper extends the earlier work [7] of the four-component decomposition and employs a rotation of the coherency matrix for more accurate image decomposition and scatterer classification.

The three-component or four-component decomposition scheme decompose polarimetric data of imaging pixel area into surface scattering (Ps: Blue), double bounce scattering (Pd: Red), volume scattering (Pv: Green), and helix scattering components. They have been successfully applied to POLSAR image analysis, however, there exist the following problems. Man-made structures orthogonal to radar illumination are decomposed into double bounce objects exhibiting "red" in the decomposed image as shown in the left corner of Fig. 1. The problem is related to the orientation of urban building blocks and houses with respect to radar direction of illumination which exhibit "green" in some building areas in case those are aligned at an oblique angle as shown in the center of Fig. 1 (Beijing). These obliquely oriented urban structures are decomposed into volume scattering objects such as trees or vegetation since the cross polarized component is dominant. 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. We see "green" building areas in almost all section of Fig. 1. It is desirable to classify obliquely oriented urban blocks/buildings as man-made structure from the classification point of view.

Fig. 1 Beijing, China, by the four-component decomposition using ALOS PALSAR Quad pol data.

In order to resolve this oriented urban problem, we present in this paper a new decomposition scheme using an idea of desying first conceived by Huynen [9]. The idea is illustrated in Fig. 2. If quad-pol data are acquired by 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 with vertical orientation. We then perform the four-component decomposition using this rotated data.

The idea of rotation has been first proposed by J. R. Huynen [8], and is cited in ref [1]. It shows that the "*Desying operation (elimination of the tilt angle) is one of the major process that full polarimetric allows one to do*". The same idea is developed in [9] where the terminology "deorientation" is used. We adopt this concept and apply it to the four-component scattering power decomposition [7].

In the following, the rotation of the coherency matrix, rotation angles, and decomposition scheme using the rotated coherency matrix are described. Some examples are provided to show the effectiveness of the new decomposition scheme.

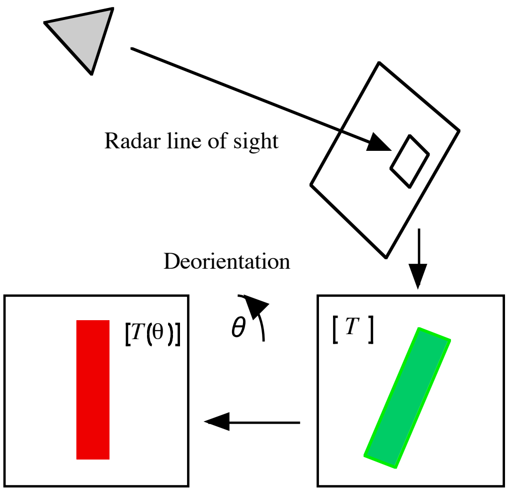


Fig. 2 Rotation of image

II. Four-component scattering power decomposition

If quad-pol. data sets are acquired, the corresponding coherency matrix can be created. Then the measured coherency matrix can be decomposed into the four terms as illustrated in Fig. 3. The scattering power, in Fig. 3, consists of the four terms: surface scattering power P_s, double bounce scattering power P_d, volume scattering power P_v, and helix scattering power P_c. The four-component scattering power decomposition algorithm displays the following advantages:

1. Easy implementation;
2. Computation time is quite small because simple calculations are required only;
3. The decomposed powers correspond to physical scattering mechanisms, i.e., surface scattering P_s, double bounce scattering P_d, volume scattering P_v, helix (circular polarization) scattering P_c;
4. Output color-coded images are directly recognized and easy to understand.

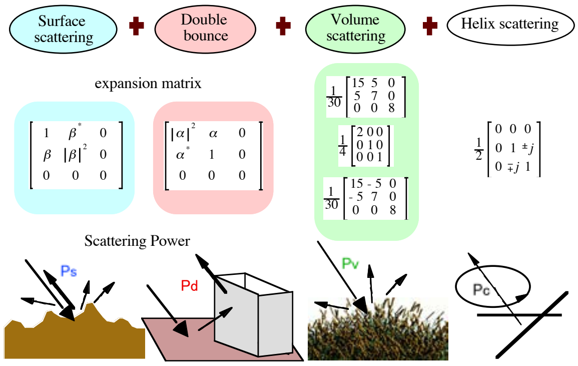


Fig. 3 The four-component decomposition of scattering powers Ps, Pd, Pv, and Pc

III. Rotation of coherency matrix

In actual radar observations, the objects under imaging are rotated about the radar line of sight. Since the decomposition scheme is carried out using the expansion matrices with no rotation as shown in Fig. 3, it seems better to rotate the polarimetric matrices to the normal direction in the decomposition stage, i. e. polarization ellipse is aligned with vertical or horizontal directions (Fig. 2).

Assume the measured coherency matrix as

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

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

$$[\,T\,(\theta)\,] = [R_P(\theta)]\,[\,T\,]\,[R_P(\theta)]^{\dagger} \quad (2)$$

$$[\,R_p\,(\theta)\,] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix} \quad (3)$$

We denote the elements of the rotated coherency matrix as

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

There seem to exist two methods for rotating the coherency matrix as is shown next in *A*. and *B*.

A. T13 rotation

The term $T_{13}(\theta)$ is zero for all expansion matrices as presented in Fig. 3.

One of rotations is to enforce $\quad T_{13}(\theta) = 0 \quad (5)$

If we use one of the Huynen parameters [7], the rotation angle becomes

$$2\theta = \tan^{-1}\left(\frac{H + jG}{C - jD}\right) \qquad (6)$$

Since (6) is complex, the angle is derived by taking the real part of (6). This rotation, however, causes some noisy effect in the resultant image.

B. T33 rotation

Another important aspect is the minimization of the cross-polarized term as anticipated from Fig. 2. By rotation of T33, the cross-polarized component will be minimized. T33 term can be written as

$$T_{33}(\theta) = T_{33}\cos^2 2\theta - \mathrm{Re}\left(T_{23}\right)\sin 4\theta + T_{22}\sin^2 2\theta \quad (7)$$

The rotation angle can be derived from the derivative with respect to θ: $\quad T_{33}'(\theta) = 0$

$$\theta = \frac{1}{4}\tan^{-1}\left(\frac{2\,\mathrm{Re}\left(T_{23}\right)}{T_{22} - T_{33}}\right), \; -\frac{\pi}{4} < \theta < \frac{\pi}{4} \qquad (8)$$

This expression is equivalent to

$$\theta = \frac{1}{4}\tan^{-1}\left(\frac{\langle E\rangle}{\langle B\rangle}\right) \qquad (9)$$

using Huynen parameters [8]. The expression (8) is of the same form as the phase of the correlation coefficient in the circular polarization basis [1, 2, 10].

VI. New Four-Component Decomposition and Decomposed Results

A rotated coherency matrix can be created using (8). We apply the four-component decomposition to this rotated coherency matrix using T33 rotation. The decomposition algorithm is shown in the flow-chart of Fig. 4. Note that all terms are derivable directly from the coherency matrix elements.

Fig. 5 shows decomposed imagery of Beijing, China after rotation of Fig. 1. The quad-pol data set used here was acquired by ALOS-PALSAR on April 2, 2009 (ALPSRP169870790_P1.1). The resolution is 30 m in the range and 5 m in the azimuth direction.

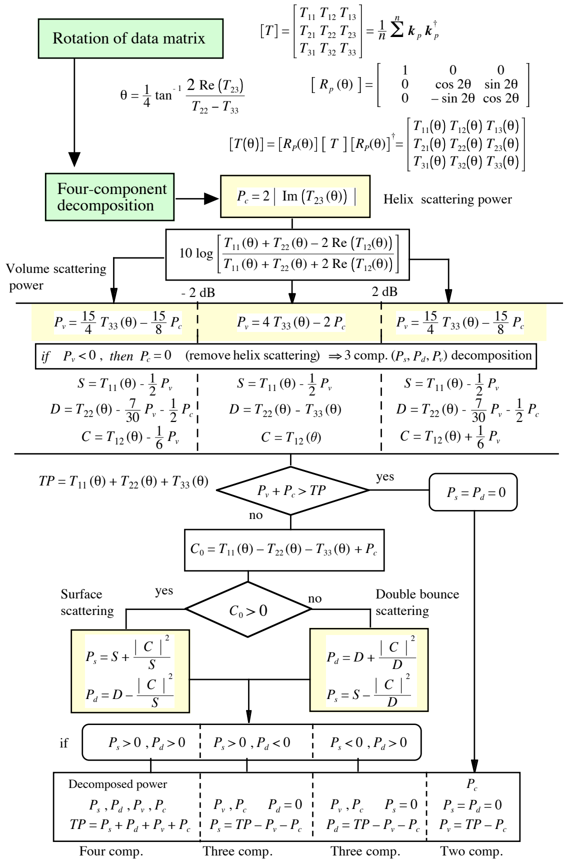
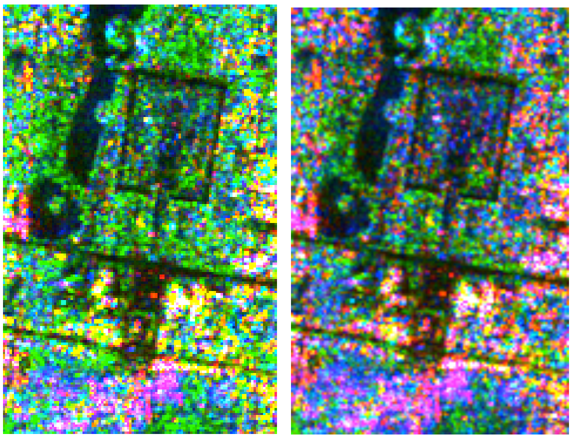


Fig. 4 Four-component scattering power decomposition algorithm using rotated coherency matrix

Fig. 5 Decomposition after T33 rotation for Fig. 1

The area of Beijing contains heterogeneous objects such as oriented urban buildings in certain directions, vegetation, crop fields (dark area), mountains covered with trees, etc. Green areas of the center of urban in Fig.1 is decomposed into red or close to red or pink in Fig. 5. This means the oriented urban block turned into red (double bounce scattering) although they are oriented in oblique directions. The mountain forest area remains the same after the rotation. This shows it is possible to discriminate vegetation areas from oriented urban areas by this new four-component decomposition with T33 rotation.

A close-up image of Forbidden city and Tian-men Square are compared in Fig. 6 for more detailed comparison. It is seen "green" areas in (a) are turned into "red or pink" in (b), which seems correct from the optical image since these areas are densely built up urban areas, and "green" are covered by trees in actual situation.



(a) before rotation (b) after rotation

Fig. 6 Close-up image of Forbidden city and Tian-men Square, Beijing, before and after T33 rotation.

VII. 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. The decomposition algorithm is provided using coherency matrix elements only. This method is quite simple and effective. It is successfully carried out to ALOS-PALSAR data and discriminated oriented urban blocks and vegetation as different scattering objects which previously were difficult to be discriminated.

Acknowledgment

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References

[1] J. S. Lee and E. Pottier, *Polarimetric radar imaging from basics to applications*, CRC Press, 2009

[2] S. R. Cloude, *Polarisation*, Oxford Press, 2009

[3] S. R. Cloude and E. Pottier, "A review of target decomposition theorems in radar polarimetry," *IEEE Trans. Geosci. Remote Sens.*, vol. 34, no. 2, pp. 498-518, Mar. 1996.

[4] E. Pottier, and J. S. Lee, "Application of the <<H/A/$\overline{\alpha}$>> polarimetric decomposition theorem for unsupervised classification of fully polarimetric SAR data on the Whishart distribution," *Proceeding of EUSAR2000*.

[5] A. Freeman, and S. Durden, "A three-component scattering model for polarimetric SAR data," *IEEE Trans. Geosci. Remote Sens.*, vol. 36, no. 3, pp. 963-973, May 1998.

[6] Y. Yamaguchi, et. al., "Four-component scattering model for polarimetric SAR image decomposition," *IEEE Trans. Geosci. Remote Sens.*, vol. 43, no. 8, pp. 1699-1706, Aug. 2005.

[7] Y. Yajima, et. al., "POLSAR image analysis of wetlands using a modified four-component scatter ing power decomposition," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 6, pp. 1667-1773, 2008

[8] J. R. Huynen, Phenomenological theory of radar targets, Ph.D Thesis, University of Technology, Delft, The Netherlands, 1970

[9] F. Xu and Y. Q. Jin, "Deorientation theory of polarimetric scattering targets and application to terrain surface classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 43, no. 10, pp. 2351-2364, Oct. 2005.

[10] J. S. Lee, D. L. Schuler, T. L. Ainsworth, E. Krogager, D. Kasilingam, W. -M. Boerner, "On the estimation of polarization orientation shifts induced by terrain slopes," *IEEE Trans. Geosci. Remote Sens.*, vol. 40, no. 1, pp. 30-41, Jan. 2002.

[11] Y. Yamaguchi, *Radar polarimetry from basics to applications*, IEICE, 2007

[12] J. S. Lee, E. Krogager, T. L. Ainsoworth, W. -M. Boerner, "Polarimetric analysis of radar signature of a manmade structure," *IEEE Geosci. Remote Sens. Letters*, vol.3, no. 4, pp. 555-559, Oct. 2006.