Polarimetric Synthetic Aperture Radar: Theory and Applications

Yoshio Yamaguchi
Dept. of Information Eng., Niigata University, 950-2181 Japan, yamaguch@ie.niigata-u.ac.jp

Abstract
Scattering power decomposition theory and some images of fully polarimetric synthetic aperture radar data are presented for disaster monitoring. Utilization of fully polarimetric data can derive full color images with red–green–blue color coding, red for the double-bounce power, green for the volume scattering power, and blue for the surface scattering power, for which each color brightness corresponds to the magnitude. Since disaster causes the change of each scattering power, it becomes easy for everyone to recognize the change by color in the decomposition image when time series data sets are available. By applying the four-component scattering power decomposition to fully polarimetric data acquired with Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR), we present several images for natural disaster monitoring on volcano activity, snow accumulation, land slide and tsunami effect caused by great earthquake. It is seen in the polarimetric decomposition images that most disaster areas show increasing surface scattering power compared to those in normal situations.

Keywords: Polarimetric Synthetic Aperture Radar, Scattering power decomposition

I. Introduction

Since the launch of ALOS-PALSAR in 2006, a large number of fully polarimetric (Quad-pol) data sets have been acquired from space [1]-[2]. Although the fully polarimetric mode is hitherto an experimental one, it has provided us with precious data sets of various places spread over the planet earth. The total number of scenes exceeds more than 274,000.

There are various image analysis methods for fully polarimetric data sets [3]-[8]. The representative and fundamental methods are based on incoherent analysis dealing with ensemble averaging of several pixels retaining the second order statistics of polarimetric information. The most frequently used method is the H-Alpha-Anisotropy developed by Cloude and Pottier [3]-[5] based on the eigenvalues of coherency matrix. The second one is the scattering power decomposition method [6]-[8] based on physical scattering models, which was first developed by A. Freeman and S. Durden [6]. The current paper describes the four-component decomposition with rotation of the coherency matrix for more accurate polarimetric synthetic aperture radar (POLSAR) image decomposition and scatterer classification.

The scattering power decomposition scheme divides polarimetric data of the imaging pixel area into surface scattering, double bounce scattering, volume scattering, and helix scattering components. These scattering powers are calculated very easily, and are used to compose full color images with RGB color-coding. They have been successfully applied to POLSAR image analysis since color-coded images are easier to understand, and since each color represents a specific scattering mechanism.

II. Scattering Power Decomposition

If scattering matrix data set of the imaging pixel area is acquired, the corresponding coherency matrix can be created, which retains the second order statistics of polarimetric information. The ensemble average of the coherency matrix is given as

$$\langle [T] \rangle = \langle \boldsymbol{k}_P \boldsymbol{k}_P^{\dagger} \rangle \quad \text{, with} \quad \boldsymbol{k}_P = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{bmatrix} \tag{1}$$

where † denotes complex conjugation and transposition, < > denotes ensemble average.

Then the measured coherency matrix is rotated by the angle $\quad 2\theta = \frac{1}{2}\tan^{-1}\left(\frac{2\,\mathrm{Re}\,(T_{23})}{T_{22} - T_{33}}\right) \qquad (2)$

so as to minimize the T33 term in (1) using

$$\langle [\ T(\theta)\ ] \rangle = [R_p(\theta)] \langle [\ T\ ] \rangle [R_p(\theta)]^{\dagger}\ \text{, with}\ \ [\ R_p(\theta)\ ] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix} \tag{3}$$

Then the rotated coherency matrix (measured) is expanded into four sub-matrices which correspond to surface scattering, double bounce scattering, volume scattering, and helix scattering mechanisms

$$\langle [T(\theta)] \rangle = f_s \langle [T] \rangle_{surface} + f_d \langle [T] \rangle_{double} + f_v \langle [T] \rangle_{vol} + f_c \langle [T] \rangle_{helix} \tag{4}$$

where $f_s, f_d, f_v, and\ f_c$ are the expansion coefficients to be determined. These four terms have been derived based on the physical scattering models as shown in Fig. 1. The derivation of scattering power is provided in [8]. The algorithm for the four-component scattering power is shown in Fig. 2.

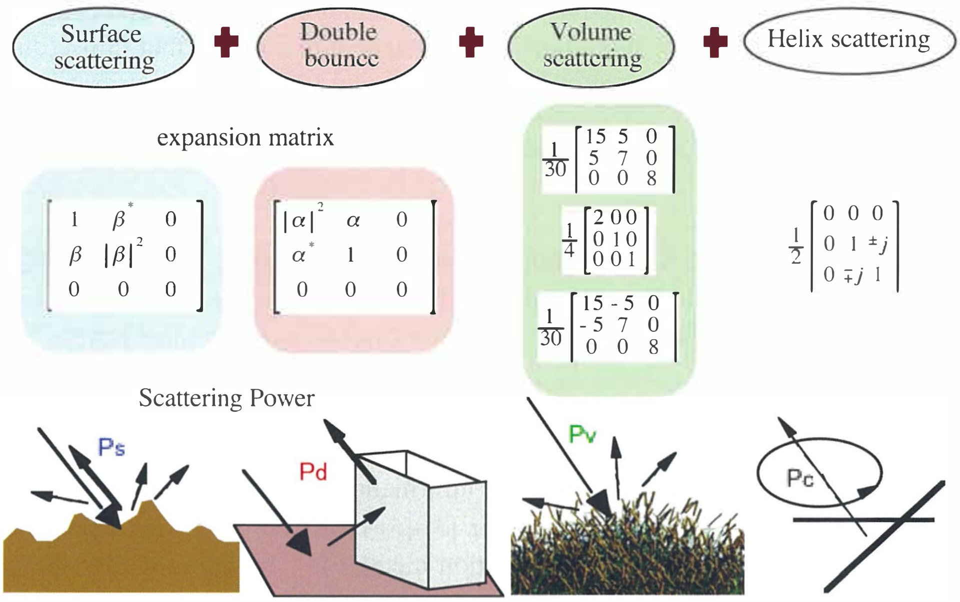


Fig. 1 The four-component decomposition of scattering powers Ps, Pd, Pv, and Pc.

III. Decomposition Results for Disaster Monitoring

A great earthquake with magnitude 9.0 hit East Japan on March 11, 2011. This disaster was accompanied by a huge tsunami which attacked the eastern seashore of Tohoku area in Japan. ALOS-PALSAR had acquired fully polarimetric data over Ishinomaki area before and after the earthquake on 20101121 and 20110408, respectively. The area was heavily destroyed not only by the earthquake by also by the tsunami. The major part of Ishinomaki-city and neighboring Onagawa-cho were completely destroyed and washed out by the tsunami. Fig. 3 shows the corresponding ALOS-PALSAR polarimetric images of Ishinomaki-city before and after the earthquake together with ground truth data. Although the second data take (April 8) was 28 days after the earthquake (March 11), it is possible to confirm several changes: red color (man-made) area turned into blue color (surface scattering due to completely washed out area by tsunami) near by seashore in Fig. 3 (a) and (b). The ground truth was carried out by Association of Japanese Geographers and Geospatial Information Authority of Japan. Fig. 3 (c) shows the extent of disaster area with blue indicating destroyed by tsunami and with orange indicating flooded by tsunami. The legend color "orange" in Fig. 3 (c) denotes the flooded area where the tsunami hit. But there still remain some buildings/houses and man-made structures after the tsunami. The "blue" color in Fig. 3 (c) denotes the area where almost all buildings/houses and man-made structures were collapsed/destroyed and washed by the tsunami, leaving bare suface on the ground. We can see fairly well correspondence in Fig. 3 (b) and (c).

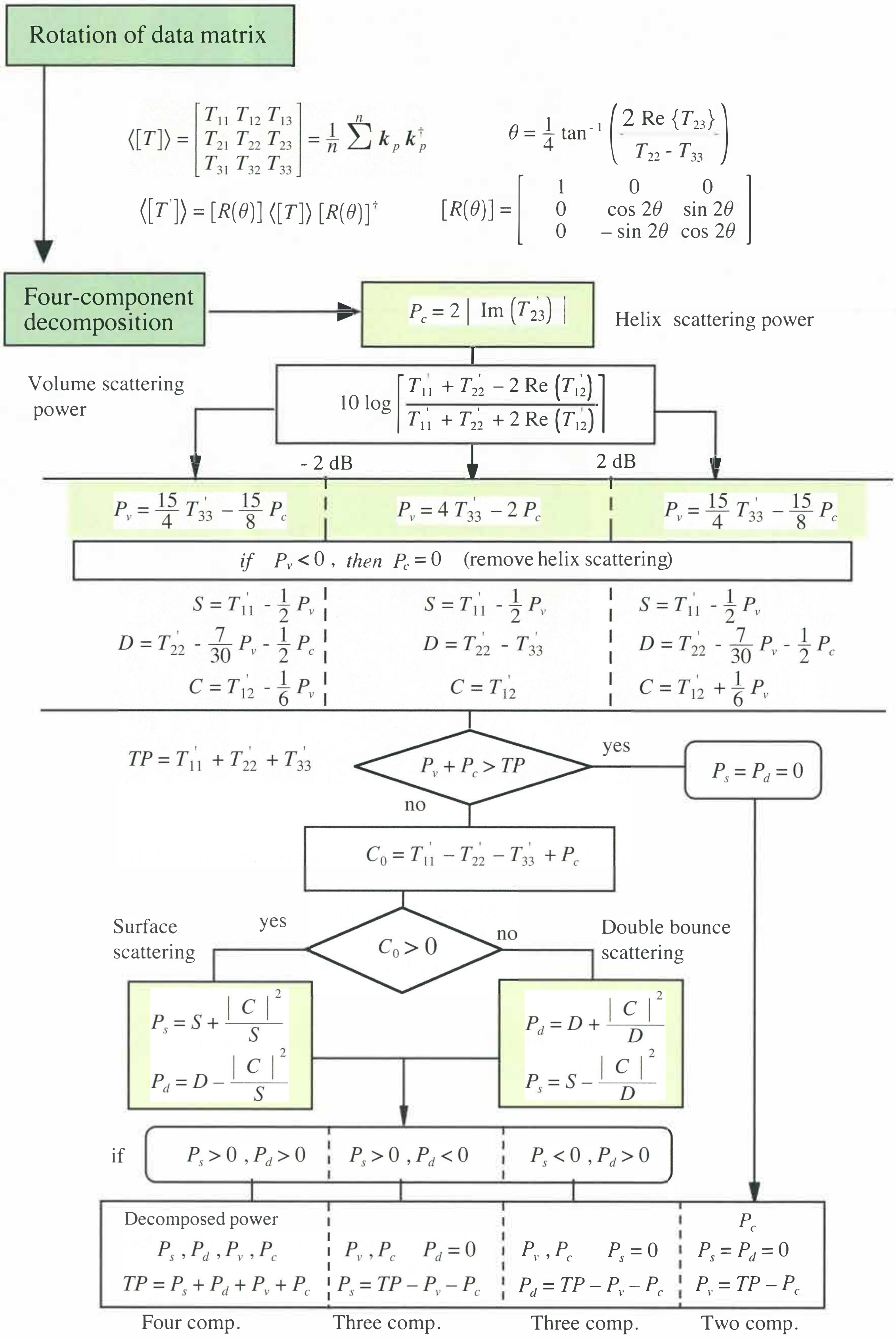
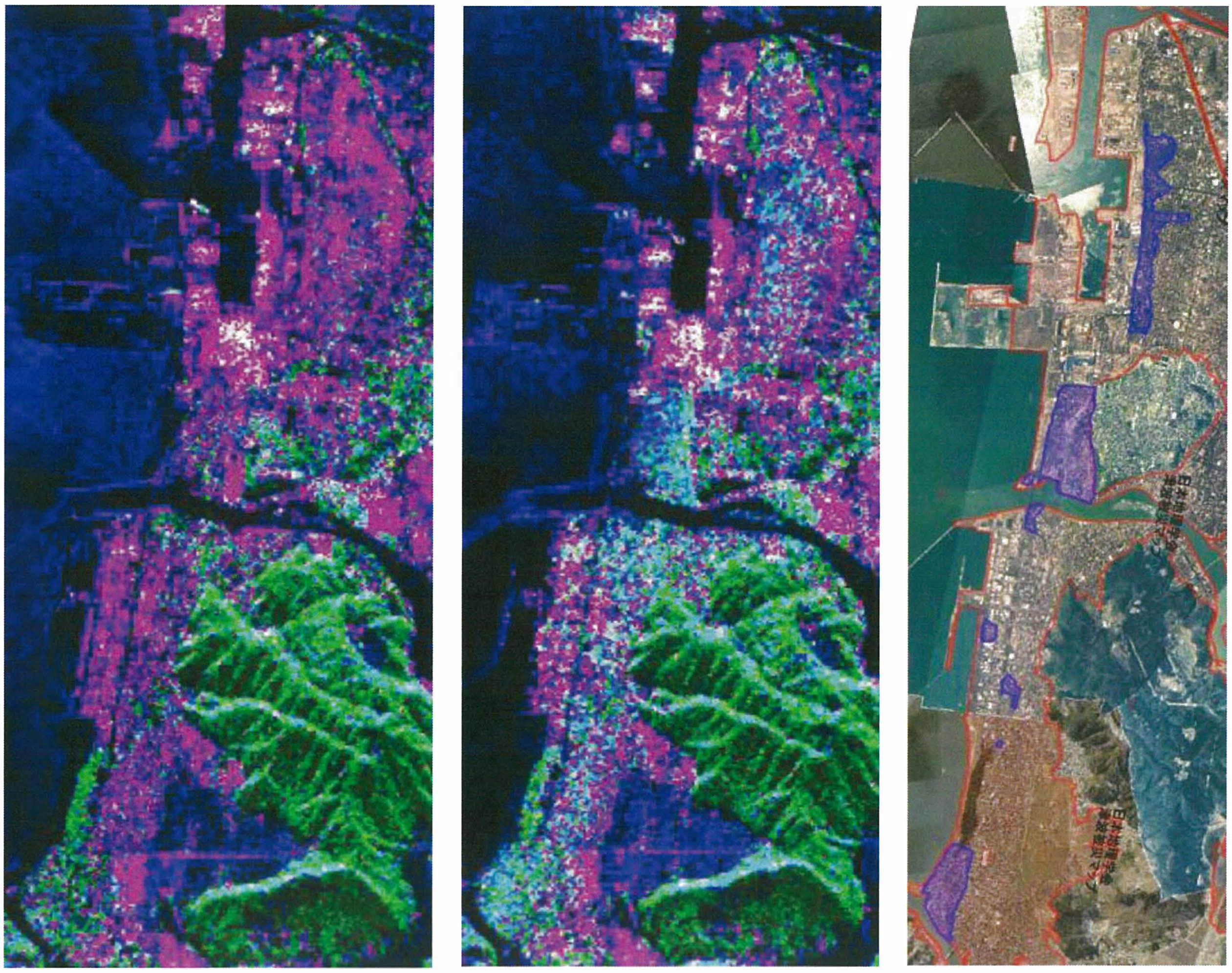


Fig. 2 Four-component scattering power decomposition algorithm using rotated coherency matrix



(a) (b) (c)

Fig. 3 Ishinomaki area suffered from tsunami caused by great earthquake of East Japan 2011. (a) before, (b) after the earthquake and tsunami. Color composite images are generated by scattering power decomposition with surface scattering (Blue), double bounce scattering (Red), and volume scattering (Green), (c) ground truth data: Blue color areas show totally destroyed areas by tsunami. Orange color denotes the area flooded by tsunami, provided by Association of Japanese Geographers, and Geospatial Information Authority of Japan.

IV. Concluding remarks

It is seen in the polarimetric decomposition images that most disaster areas show increasing surface scattering power compared to those in normal situations.

References

[1] [Online]. Available: http://www.eorc.jaxa.jp/ALOS/en/about/palsar.htm

[2] [Online]. Available: http://www.palsar.ersdac.or.jp/e/index.shtml

[3] J. S. Lee and E. Pottier, *Polarimetric radar imaging from basics to applications*, (398 pages), CRC Press, 2009

[4] 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.

[5] 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," *Proc. of EUSAR2000*, pp. 265-268, May 2000

[6] 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.

[7] Y. Yamaguchi, T. Moriyama, M. Ishido, and H. Yamada, "Four-component scattering model for polarimetric SAR image decomposition," *IEEE Trans. Geosci. Remote Sens.*, vol. 43, no. 8, pp. 1699-1706, Aug. 2005.

[8] Y. Yamaguchi, A. Sato, W. -M. Boerner, R. Sato, H. Yamada, "Four-component scattering power decomposition with rotation of coherency matrix," *IEEE Trans. Geosci. Remote Sens.*, vol. 49, no. 6, pp. 2251-2258, June 2011.