Institute of Electronics, Information, and Communication Engineers

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Four-Component Scattering Model for Polarimetric SAR Image Decomposition based on Covariance Matrix

Yoshio YAMAGUCHI[†], Toshifumi MORIYAMA[††], Motoi ISHIDO[†], Hiroyoshi YAMADA[†]
[†] Dept. of Information Engineering, Niigata University
[††] NICT

1. Introduction

Terrain and land use classification is one of the most important applications in Polarimetric Synthetic Aperture Radar (POLSAR) sensing. Excellent works [1]-[2] have been proposed to classify terrain based on polarimetric statistical characteristics in POLSAR image analysis. Three component scattering model [1] has been successfully applied to decompose scattering mechanisms under the reflection symmetry condition $\langle S_{HH} S_{HV}^* \rangle \approx \langle S_{VV} S_{HV}^* \rangle \approx 0$.

In this report, a four-component scattering model is proposed to decompose POLSAR image [3]. Circular polarization power is added to the three (i.e., surface, double bounce, and volume) component scattering model. Covariance matrix approach is used to deal with non-reflection symmetric scattering case $\langle S_{HH} S_{HV}^* \rangle \neq 0$. Since this scheme includes the reflection symmetry condition $\langle S_{HH} S_{HV}^* \rangle \approx 0$, it is applicable to general scattering case (see Fig.1). This circular polarization generation is taken into account for the term $\langle S_{HH} S_{HV}^* \rangle$, which is relevant to man-made targets.

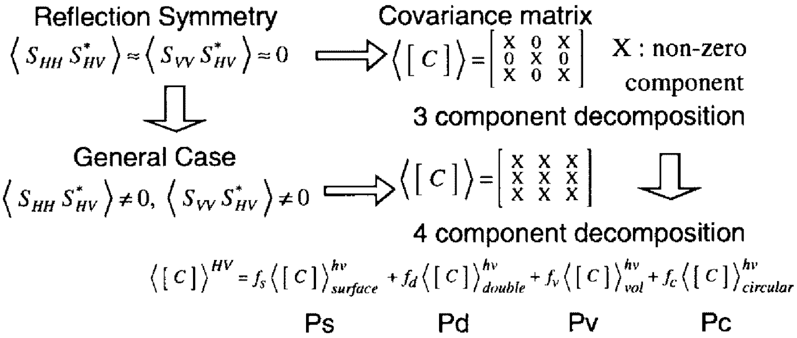

Fig.1　4-component decomposition

2. Covariance Matrix expansion

To derive polarimetric scattering characteristics in POLSAR image, it is necessary to evaluate the second order statistics of scattering matrix. For this purpose, we choose ensemble covariance matrix (1) and expand the matrix into four components as (2)

$$\langle [C] \rangle = \begin{bmatrix} \langle |S_{HH}|^2 \rangle & \sqrt{2}\langle S_{HH} S_{HV}^* \rangle & \langle S_{HH} S_{VV}^* \rangle \\ \sqrt{2}\langle S_{HV} S_{HH}^* \rangle & 2\langle |S_{HV}|^2 \rangle & \sqrt{2}\langle S_{HV} S_{VV}^* \rangle \\ \langle S_{VV} S_{HH}^* \rangle & \sqrt{2}\langle S_{VV} S_{HV}^* \rangle & \langle |S_{VV}|^2 \rangle \end{bmatrix} \tag{1}$$

$$= f_s \begin{bmatrix} |\beta|^2 & 0 & \beta \\ 0 & 0 & 0 \\ \beta^* & 0 & 1 \end{bmatrix} + f_d \begin{bmatrix} 1 & 0 & \alpha^* \\ 0 & 0 & 0 \\ \alpha & 0 & |\alpha|^2 \end{bmatrix} + \frac{f_v}{15} \begin{bmatrix} 8 & 0 & 2 \\ 0 & 4 & 0 \\ 2 & 0 & 3 \end{bmatrix} + \frac{f_c}{4} \begin{bmatrix} 1 & \pm j\sqrt{2} & -1 \\ \mp j\sqrt{2} & 2 & \pm j\sqrt{2} \\ -1 & \mp j\sqrt{2} & 1 \end{bmatrix} \tag{2}$$

where < > is ensemble average in the image processing, and $\alpha, \beta, f_s, f_d, f_v,$ *and* f_c are unknowns to be determined. For mathematical modeling in (2), the 4 covariance matrices are corresponding to double bounce, surface, volume, and the circular polarization power components, respectively. Note that the traces of third and fourth covariance matrices are unity so that the contribution to the total power is represented by the coefficients, f's. As regards the circular polarization power, we pick up the term $\mathrm{Im}\langle S_{HV} S_{VV}^* \rangle$ based on theoretical "Helix" covariance matrix. If the magnitude of circular polarization power is f_c , the corresponding magnitude of $\mathrm{Im}\langle S_{HV} S_{VV}^* \rangle$ becomes $f_c/4$. We take the average of $\langle S_{HH} S_{HV}^* \rangle$ and $\langle S_{HV} S_{VV}^* \rangle$ in order to avoid conflict of $\langle S_{HH} S_{HV}^* \rangle \neq \langle S_{HV} S_{VV}^* \rangle$ in the measured data., so that

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$$\frac{f_c}{4}=\frac{1}{2}\left|\ \mathrm{Im}\left\{\left\langle S_{HH}S_{HV}^{*}\right\rangle+\left\langle S_{HV}S_{VV}^{*}\right\rangle\right\}\right| \qquad (3)$$

In addition, the volume scattering covariance matrix is slightly modified by the change of probability density function for cloud of oriented wires, rather than uniform distribution [1].

$$p(\theta)=\begin{cases}\frac{1}{2}\sin\theta & for\ 0<\theta<\pi\\ 0 & for\ \pi<\theta<2\pi\end{cases}$$

The comparison of the elements in (1) and (2) yields 5 equations with 6 unknowns $\alpha, \beta, f_s, f_d, f_v, and\ f_c$. Since we can determine f_c and f_v directly by measured value, we have 3 equations with 4 unknowns which can be obtained in the same manner as in [1]. The scattering powers P_s, P_d, P_v, P_c are obtained as

$$P_s=f_s\left(1+|\beta|^2\right),\ P_d=f_d\left(1+|\alpha|^2\right),\ P_v=f_v\ ,\ P_c=f_c \qquad (4)$$

$$P_{total}=P_s+P_d+P_v+P_c=\left\langle|S_{HH}|^2+2|S_{HV}|^2+|S_{VV}|^2\right\rangle\ . \qquad (5)$$

corresponding to surface, double bounce, volume, and circular polarization powers, respectively.

3. Example

This scheme is applied to Pi-SAR L-band data set. The area is Niigata-city, as shown in Fig.2. The scattering powers corresponding to Ps (Blue) , Pd (Red), Pv (Green) are shown in Fig.2 (b) and Pc (White) in (c). The details of various images together with quantitative analyses will be shown in the presentation.

4. Concluding Remarks

A four component scattering model for polarimetric SAR image decomposition is proposed. Circular polarization power is added to the three scattering model. This circular polarization component corresponds to the imaginary part of $\left\langle S_{HH}S_{HV}^{*}\right\rangle$ which often appears in complex urban area and disappears in natural distributed target. In addition, the volume scattering covariance matrix is slightly modified, which agrees with measured data.

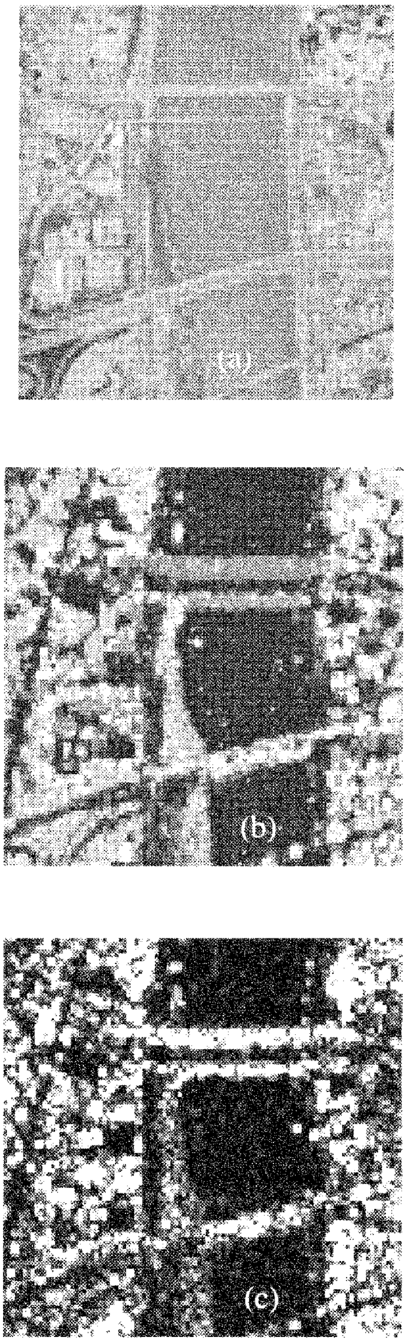

Fig.2 (a) Areial Photo, (b) Ps, Pd, Pv
(c) Pc

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The authors are grateful to Pi-SAR data provided by NICT and JAXA.
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