A Study on Extraction of Urban Areas from Polarimetric Synthetic Aperture Radar image

Toshifumi Moriyama, Seiho Uratsuka,
Toshihiko Umehara, Makoto Satake,
Akitsugu Nadai, Hideo Maeno and Kazuki Nakamura
NICT
4-2-1, Nukui-Kitamachi, Koganei, Tokyo, Japan
e-mail toshi.moriyama@nict.go.jp

Yoshio Yamaguchi
Faculty of Engineering, Niigata University
Ikarashi 2-8050, Niigata 950-2181, Japan

***Abstract*—This paper discusses the polarimetric correlation coefficient to extract the urban areas from polarimetric Synthetic Aperture Radar (POLSAR) image. For classification of POLSAR image, several methods have been proposed to extract polarimetric feature, such as Polarimetric Entropy-Alpha, three-component scattering model, Huynen parameters and so on. However, there is a possibility that the polarimetric correlation coefficient has a potential for the objective of this paper, too. In order to verify the capability of polarimetric correlation coefficient, we examine the behavior of this coefficient between the urban areas and the natural distributed areas with respect to the several polarimetric scattering models and the difference of polarization basis. Moreover, we apply the polarimetric correlation coefficient to the actual polarimetric SAR data acquired by Pi-SAR/X-SAR.**

Keywords-POLSAR; classfication; urban areas; polarimetric correlation coefficient; scattering model

I. INTRODUCTION

Polarimetric Synthetic Aperture Radar (POLSAR) image contains both the urban areas and the natural distributed areas. It is well known that the polarimetric information (which is both the amplitude and the phase) is useful for classification and segmentation in the natural distributed areas [1][2]. Many examples of these objectives using polarimetric SAR data are introduced. For example, Polarimetric Entropy-Alpha is one of the powerful tools to estimate the statistical polarimetric SAR data such as Coherency matrix, Covariance matrix, etc. However, it is difficult to apply the polarimetric analysis techniques to extraction of urban areas from polarimetric SAR image, because the polarimetric backscatter from urban areas varies highly with orientation, shape and distribution of buildings and houses, and street patterns [3]. These effects influence other techniques using single polarimetric SAR data such as Neural network, Fuzzy, Maximum-likelihood approach, etc.

In this paper, an extraction method of urban areas by the polarimetric correlation coefficient is examined. We have investigated the behavior of polarimetric correlation coefficient by using several polarimetric scattering models in the linear (HV) and the circular (RL) polarization basis [4]. The one of key points to extract urban areas is the following characteristics (azimuthal symmetry [5]) as,

$<S_{HH}S_{HV}^*>=<S_{HV}S_{VV}^*>=0$ for natural distributed areas

$<S_{HH}S_{HV}^*>\neq 0$, $<S_{HV}S_{VV}^*>\neq 0$ for urban areas

where < > and * are ensemble average operation and complex conjugate, respectively. Another characteristic is $<S_{RR}S_{LL}^*>$ in circular basis. The backscatter arising from artificial and natural terrains can be generally expressed combining the responses of surface scattering, double-bounce scattering and volume scattering. Since $<S_{RR}S_{LL}^*>$ of volume scattering which is mainly generated from natural distributed areas becomes zero, this index is useful for detecting of the urban areas, too. In addition, we also use the Radar Cross Section (RCS) of HV polarization state to improve the extraction accuracy of urban areas. These characteristics of POLSAR data is applied to the actual X-band SAR data acquired by Pi-SAR (Polarimetric and Interferometric SAR was developed by NICT and JAXA.) [6] and is demonstrated to be suitable for extraction of urban areas from polarimetric SAR image.

II. RADAR POLARIMETRY

In the polarimetric synthetic aperture radar, if polarimetric measurement is conducted in the linear (HV) basis, the set of polarimetric scattering coefficients at each pixel of SAR image provides the scattering matrix [S(HV)].

$$[S(HV)] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \quad (1)$$

where H and V mean the horizontal and the vertical polarization. For the reciprocal backscattering case, S_{HV} is identical with S_{VH}. The scattering matrix contains useful polarimetric feature for classification and recognition of targets and terrains. However, it is difficult to obtain useful polarimetric feature from the scattering matrix directly. To overcome this problem, there are several feature extraction methods based on the Covariance, Coherency, Mueller matrix and so on. In order to extract polarimetric feature from the scattering matrix, we use polarimetric correlation coefficient in this paper.

III. POLARIMETRIC SCATTERING CHARACTERISTICS

The various terrains on the earth are roughly divided into two areas. One is the natural distributed areas, i.e., fields, woods and the sea. The other is the urban areas which consist of many houses and buildings. The polarimetric scattering characteristics of two areas are investigated in some literatures. The objective of these literatures is to generate the scattering response of a known target and to retrieve the target's electromagnetic properties from radar signal. These trials are very important for the remote sensing. For example, in the natural distributed areas case, Durden and Freeman [2] suggested that the combination of three simple scattering mechanisms based on the physical scattering model is useful for retrieving the polarimetric scattering characteristics from the measured polarimetric SAR data. In the urban areas case, Franceschetti and et al. [3] provided a geometric and electromagnetic model of a typical element of urban structure based on the high frequency technique. According to the above-mentioned literatures, the polarimetric scattering characteristics between the natural distributed areas and the urban areas are described as follows.

A. Natural distributed areas

Durden and Freeman's Decomposition divides the measured covariance matrix into three dominant scattering mechanisms, i.e., surface, volume and double-bounce scattering. These three mechanisms are the principal elements in the backscattering from a natural terrain such as forests. A scattering matrix of these mechanisms is given by

$$[S_{surface}]=\begin{bmatrix}\beta & 0\\ 0 & 1\end{bmatrix},\quad [S_{double-bounce}]=\begin{bmatrix}\alpha & 0\\ 0 & 1\end{bmatrix} \qquad \text{(2a,b)}$$

where α and β are a ratio of HH backscatter of VV backscatter of surface and double-bounce mechanisms, respectively. In volume scattering case, the canopy consists of many dipoles (such as leaves, twigs and branches) randomly oriented in azimuth direction. The scattering matrix of a dipole is written by

$$[S_{dipole}]=\begin{bmatrix}\cos^2\theta & \sin\theta\cos\theta\\ \sin\theta\cos\theta & \sin^2\theta\end{bmatrix} \qquad \text{(2c)}$$

where θ is an orientation angle in a plane orthogonal to a radar line of sight. It is assumed that Durden and Freeman's Decomposition satisfies the following condition as

$$\langle S_{HH}S_{HV}^{*}\rangle=\langle S_{HV}S_{VV}^{*}\rangle\approx 0\,. \qquad (3)$$

This condition is well known as the property of azimuthal symmetry [5]. The three scattering models and the azimuthal symmetry are very important characteristic for considering a scattering wave from the natural distributed areas.

B. Urban areas

The urban areas consist of various houses and buildings which are a man-made target. The radar cross section (RCS) of man-made target can be usually calculated by coherently combining the responses of the three simple models which are single-, double- and triple-bounce scattering mechanisms. The single-bounce scattering is relevant to the rough ground,

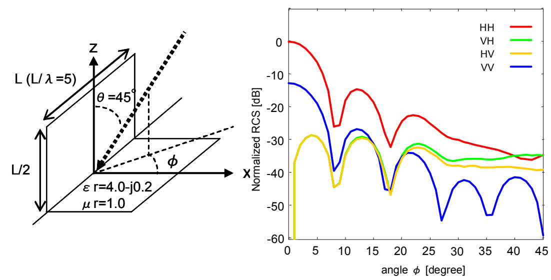

Figure 1. RCS pattern of dihedral refector at 10GHz.

building roofs and vertical walls. The double-bounce scattering is caused by dihedral structures formed by vertical walls and the ground. The triple-bounce scattering is generated by trihedral structures formed by wall-ground-wall. These scattering mechanisms can be treated by two scattering matrixes which are the odd- and even-bounce scattering. The scattering matrix of odd- and even-bounce scattering can be given by [4]

$$[S_{odd}]=\begin{bmatrix}\beta & 0\\ 0 & 1\end{bmatrix},\quad [S_{even}]=\begin{bmatrix}\gamma & \rho\\ \rho & 1\end{bmatrix} \qquad \text{(4a,b)}$$

where γ and ρ are a ratio of HH and HV backscatters to VV backscatter. The single- and triple-bounce models are considered as same scattering matrix (odd-bounce type). Figure 1 shows the RCS pattern of dielectric dihedral reflector as a function of azimuth angle, when radar look angle is 45°. We assume that the scattering matrix of double-bounce scattering (even-bounce type) mechanism can be expressed as eq.(4b) based on the result of Fig.1. The RCS pattern of Fig.1 indicates that a generation of cross-polarized response in urban areas is mainly related to the double-bounce structures and the like-polarized response is affected by azimuth angle. Moreover, equation (4b) provides a possibility that the polarimetric correlation between like- and cross-polarized channels doesn't become zero, e.g., $<S_{HH}S_{HV}^{*}>\neq 0$, $<S_{HV}S_{VV}^{*}>\neq 0$. Therefore, the scattering characteristic of the urban areas is very different from that of the natural distributed areas.

IV. Polarimetric Correlation Coefficient

The polarimetric correlation coefficient is defined by

$$Cor(S_{AB},S_{XY})=\frac{\langle S_{AB}S_{XY}^{*}\rangle}{\sqrt{\langle S_{AB}S_{AB}^{*}\rangle\langle S_{XY}S_{XY}^{*}\rangle}} \qquad (5)$$

where the subscripts AB and XY mean the polarization states such as HH, HV and VV in HV linear polarization basis. If the linear polarization basis (HV) is transformed to the circular polarization basis (RL), the components of scattering matrix in RL basis are obtained from the following equations as,

$$
\begin{aligned}
S_{RR} &= (S_{HH} - S_{VV} - j2S_{HV})/2 \\
S_{LL} &= (S_{VV} - S_{HH} - j2S_{HV})/2 \\
S_{RL} &= S_{LR} = -j(S_{HH} + S_{VV})/2
\end{aligned} \tag{6}
$$

where R and L are the right and the left circular polarization, respectively. Thus, the polarimetric correlation coefficient in RL basis can be calculated very easy. By using the simple scattering models described in Sec. III, we try to confirm the behavior of polarimetric correlation coefficient in a linear and a circular polarization basis, respectively. It is expected that a polarimetric correlation coefficient becomes useful index to distinguish between the urban areas and the natural distributed areas.

A. Linear polarization basis

In the linear polarization basis, the key point to extract the polarimetric characteristic from various terrains is the following properties as,

$\langle S_{HH}S_{HV}^*\rangle = \langle S_{HV}S_{VV}^*\rangle = 0$ for natural distributed areas

$\langle S_{HH}S_{HV}^*\rangle \neq 0$, $\langle S_{HV}S_{VV}^*\rangle \neq 0$ for urban areas.

Since various terrains in the natural distributed areas indicate the property of azimuthal symmetry, the polarimetric correlation coefficient between like- and cross-polarized channels is close to zero. On the other hand, one of the dominant scattering mechanisms in urban areas is an even-bounce scattering whose matrix is expressed in eq.(4b). The even-bounce scattering mechanism doesn't indicate the property of azimuthal symmetry. Therefore, the polarimetric correlation coefficient between like- and cross-polarized channels of the urban areas is higher than that of the natural distributed areas. However, when a direction of street pattern is orthogonal to a radar line of sight, this index cannot be used, because ρ in eq.(4b) becomes zero.

B. Circular polarization basis

In the circular polarization basis, it is expected that a polarimetric correlation coefficient between RR and LL indicates a difference of scattering characteristics between the urban areas and the natural distributed areas. In a forest and vegetable field, a volume scattering becomes dominant scattering mechanism. In order to evaluate $Cor(S_{RR},S_{LL})$ of volume scattering, it is necessary to calculate the following scattering quantity from eq.(2c).

$$
\left\langle S_{XY}S_{AB}^*\right\rangle = \int_0^{2\pi} S_{XY}(\theta)S_{AB}^*(\theta)P(\theta)d\theta \tag{7}
$$

where $P(\theta)$ is a probability density function of a dipole orientation distribution. In this calculation, it is assumed that an orientation distribution of dipole is uniform. Thus, the $Cor(S_{RR},S_{LL})$ of volume scattering becomes zero. On the other hand, from eq.(4a), (4b), $\langle S_{RR}S_{LL}^*\rangle$ of odd- and even-scattering mechanisms in the urban areas is derived as follows,

$$
\langle S_{RR}S_{LL}^*\rangle \approx -\langle S_{RR}S_{RR}^*\rangle = -\langle S_{LL}S_{LL}^*\rangle. \tag{8}
$$

where we consider that cross-polarized component ρ of even-bounce scattering is close to zero, because ρ is usually very small than γ. Thus, the absolute value of $Cor(S_{RR},S_{LL})$ of odd-bounce and even-bounce scattering mechanisms is close to one. Thus, it is predicted that the polarimetric correlation coefficient between RR and LL of the urban areas is higher than that of the natural distributed areas. However, an increase of ρ caused by an angle of street pattern toward the radar line of sight reduces a usefulness of this index.

There is a possibility that the above-mentioned indices of polarimetric correlation coefficient distinguish between the urban areas and the natural distributed areas. Moreover, it is expected that a combination of polarimetric correlation coefficients between linear and circular polarization bases compensate for weakness of each index. In next session, we verify the applicability of these indices to the actual polarimetric SAR data.

V. EXPERIMENTAL RESULTS

We apply the indices of polarization correlation coefficient in linear and circular polarization basis to the Polarimetric and Interferometric Synthetic Aperture Radar (Pi-SAR) [6] data of Kobari area in Niigata city on August 20, 2003. Pi-SAR was developed by the National Institute of Information and Communications Technology (NICT) and the Japan Aerospace Exploration Agency (JAXA), and can carry out fully polarimetric observation at both X-band and L-band. In this paper, we use only X-band data. Figure 2 shows the span image of Kobari area. This image has a dimension of 4000 x 4000 pixels. The resolution of image is 1.5 [m] in both the azimuth and range direction. The Kobari area consists of Sea of Japan, pine woods (upper part), residential area (middle part) and paddy fields (lower part). Before data analysis, the average filtering of 15 x 15 windows is applied to this polarimetric data due to the reduction of phase information dispersion. In this image, there are six test areas, i.e., two residential areas, sea area, pine woods area, paddy fields area, the vegetable fields area. The two residential areas have different street patterns which are the orientation angle of about 20.5 degrees (residential area A) and 1.0 degrees (residential area B) to azimuth direction. The test area is composed of 100 x 100 pixels except for vegetable fields(40 x 40).

We compare the three average indices ($Cor(S_{RR},S_{LL})$, $Cor(S_{HH},S_{HV})$ and $Cor(S_{HV},S_{VV})$) of each test area. The result is shown in Fig.3. In sea area, the index in RL basis, $Cor(S_{RR},S_{LL})$, is about 0.9 and the indices in HV basis, $Cor(S_{HH},S_{HV})$ and $Cor(S_{HV},S_{V}V)$, are lower than 0.3. Since, in general, the scattering mechanism of sea area dominates the surface scattering, it seems that these indices provide proper results. In two residential areas, the index in RL basis is large, because the urban structure yields the even-bounce scattering which satisfies the scattering matrix of eq.(4b). However, the indices of residential area B in HV basis are small, and differ from those of residential area A. The reason is that the street pattern is parallel to the azimuth direction. Thus, ρ of eq.(4b) in residential area B is close to zero. On the other hand, three indices of paddy fields, pine woods and vegetable fields are small. These results mean that the scattering mechanism of three vegetation areas dominate the volume scattering. Figure 4 shows the image of three indices in Kobari area. It is seen that the residential areas appear clearly and the vegetation areas disappear in each image. Therefore, it is shown that three indices of polarimetric correlation coefficient are useful to discriminate between the vegetation areas and the urban areas. Moreover, there is a problem to discriminate between the residential areas and the sea area, because the both areas have a close value with respect to Cor(S_{RR},S_{LL}). In order to separate sea area and residential area, we apply the backscattering coefficient of HV polarization state to new index. By using the polarimetric correlation coefficients in linear and circular polarization basis and the HV backscattering coefficient, a classification of urban area, vegetation area and sea area is performed. The algorithm of classification uses a decision tree. The result of classification is shown in Fig.5. It can see that three areas are well classified. Therefore, it is shown that the indices of polarimetric correlation coefficient are useful to extract the urban areas from the POLSAR image.

VI. CONCLUSION

In this paper, we proposed the indices of polarimetric correlation coefficient in linear and circular polarization bases to extract useful feature from polarimetric SAR data. These indices were selected by the applicability of polarimetric analysis based on the polarimetric scattering model and the property of azimuthal symmetry. We applied this technique to Pi-SAR/X-SAR data. This technique showed the capability to discriminate between the vegetation area and the urban area.

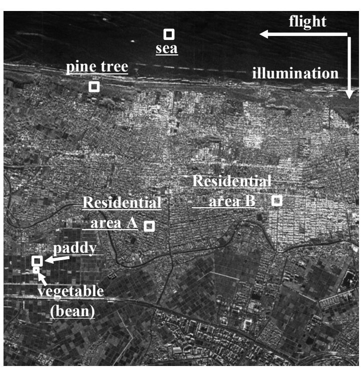

Figure 2. The span image of Kobari area in Niigata City.

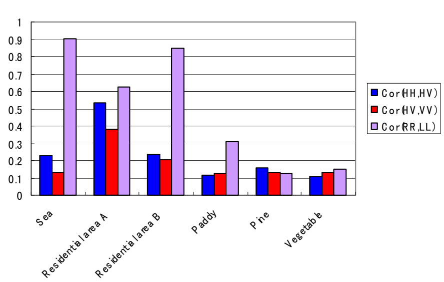

Figure 3. The comparison of indices of polarimetric correlation coefficient of each test areas.

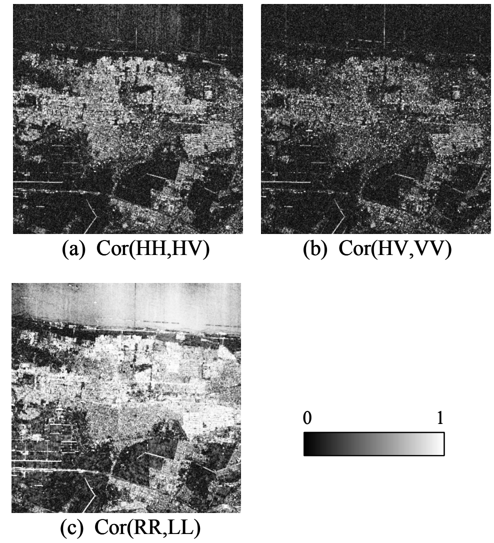

Figure 4. The image of threeindices in Kobari area.

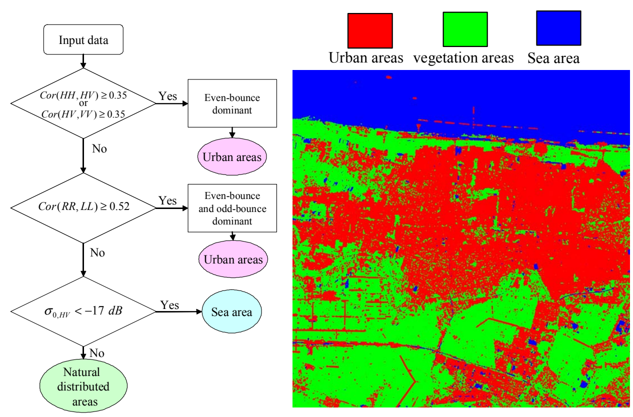

Figure 5. The classification result by decision tree.

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