

A Study on Polarimetric Correlation Coefficient for Feature Extraction of Polarimetric SAR Data

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1. Introduction

This paper discusses the polarimetric correlation coefficient to extract useful feature from polarimetric Synthetic Aperture Radar (SAR) data. Several methods have been proposed to extract polarimetric feature, such as Polarimetric Entropy-Alpha, three-component scattering model, Huynen parameters and so on^{[1][2][3]}. In this field, we are interested in polarimetric correlation coefficient^[2]. In order to verify the potential of polarimetric correlation coefficient, we examine the behavior of this coefficient with respect to the several polarimetric scattering models^[3], the property of azimuth symmetry^[4] 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^[5].

2. 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.

3. Polarimetric correlation coefficient

The polarimetric correlation coefficient is defined as^[2]

$$Cor(S_{AB}, S_{XY}) = \frac{\langle S_{AB} S_{XY}^* \rangle}{\sqrt{\langle S_{AB} S_{AB}^* \rangle \langle S_{XY} S_{XY}^* \rangle}} \quad (2)$$

where the subscripts AB and XY mean the polarization states such as HH, HV and VV in HV polarization basis, and $\langle \rangle$ is the ensemble averaging operation. This coefficient changes concerning the various targets and terrains. On the other hand, the simple scattering models are proposed to represent the radar backscatter from natural areas. Moreover, there is the assumption that the like- and cross-polarized responses in HV polarization basis are uncorrelated in the natural distributed area, i.e.,

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

This assumption is based on the expectation that the most natural targets display azimuthal symmetry. By using the simple scattering models and the assumption, we try to confirm the behavior of

polarimetric correlation coefficient in linear and circular polarization basis, respectively.

a) Circular polarization basis

Durden and Freeman proposed the three simple scattering models^[3] which are surface scatterer, double-bounce scatterer and volume scatterer from a canopy of randomly oriented dipoles. The scattering matrices of surface scatterer and double-bounce scatterer can be written as

$$[S_{surface}] = \begin{bmatrix} \beta & 0 \\ 0 & 1 \end{bmatrix} \text{ (surface scatterer case),} \quad [S_{double}] = \begin{bmatrix} \alpha & 0 \\ 0 & 1 \end{bmatrix} \text{ (double-bounce scatterer)} \quad (4a,b)$$

where α and β are a ratio of HH backscatter to VV backscatter of surface and double-bounce scatterers, respectively. In volume scatterer case, the canopy consists of many dipoles randomly oriented azimuth direction. The scattering matrix of a dipole is given by

$$[S_{dipole}] = \begin{bmatrix} \cos^2 \theta & \sin \theta \cos \theta \\ \sin \theta \cos \theta & \sin^2 \theta \end{bmatrix} \quad (5)$$

where θ is an orientation angle in a plane orthogonal to a radar line of sight. The distribution of dipole orientation is determined by probability density function $P(\theta)$. Thus, the scattering quantity of randomly oriented dipoles is derived as

$$\langle S_{XY} S_{AB}^* \rangle = \int_0^{2\pi} S_{XY}(\theta) S_{AB}^*(\theta) P(\theta) d\theta \quad (6)$$

If the liner polarization basis is transformed to the circular (RL) polarization basis, the new components of scattering matrix are obtained from following equations as

$$\begin{aligned} S_{RR} &= (S_{HH} - S_{VV} - j2S_{HV})/2 \\ S_{LL} &= (S_{VV} - S_{HH} - j2S_{HV})/2 \\ S_{RL} &= S_{LR} = -j(S_{HH} + S_{VV})/2 \end{aligned} \quad (7a,b,c)$$

where R and L are the right circular polarization and left circular polarization, respectively. We can calculate the polarimetric correlation coefficients in RL basis. From eq.(5), (6) and (7), the polarimetric correlation coefficient between RR and LL of volume scatterer, $\text{Cor}(S_{RR}, S_{LL})$, becomes zero. In this calculation, we assume that the probability density function $P(\theta)$ is a uniform orientation distribution. On the other hand, the magnitude of polarimetric correlation coefficient between RR and LL of surface and double-bounce scatterers is equal to one. Therefore, it is expected that the polarimetric correlation coefficient between RR and LL is used to discriminate between vegetation areas and urban areas, because the volume scattering is dominant scattering mechanism in the vegetation areas such as forests areas and vegetable fields, and the double-bounce scattering is main scattering mechanism in the urban area.

b) Linear polarization basis

Since various distributed targets indicate the property of azimuth symmetry^[4] in natural areas, the polarimetric correlation coefficient between like- and cross-polarized responses, $\text{Cor}(S_{HH}, S_{HV})$, $\text{Cor}(S_{HV}, S_{VV})$, is close to zero. On the other hand, the dominant scattering mechanism of urban areas is the double-bounce scattering. The double-bounce scattering mechanism from urban structures causes a generation of the cross-polarized response due to the effect of street orientation toward the radar look direction. Therefore, the simple scattering model of double-bounce scattering from urban structures can be written as

$$[S_{double \text{ in urban}}] = \begin{bmatrix} \alpha & \rho \\ \rho & 1 \end{bmatrix} \quad (8)$$

where ρ is a ratio of the cross-polarized components (HV and VH) to the VV component, and we assume that ρ is smaller than α . Therefore, the polarimetric correlation coefficients, $\text{Cor}(S_{HH}, S_{HV})$, $\text{Cor}(S_{HV}, S_{VV})$, of this scattering model is not equal to zero, and it is supposed that these polarimetric

correlation coefficients become higher than those of natural areas.

It is possible that the above proposed indices of polarimetric correlation coefficient distinguish between the natural distributed area and urban area. In next section, we verify the applicability of these indices to the actual polarimetric SAR data.

4. Experimental results

We apply the proposed indices of polarization correlation coefficient to the Polarimetric and Interferometric Synthetic Aperture Radar (Pi-SAR) data^[5] of Kobari area in Niigata city on August 20, 2003. Pi-SAR was developed by the Communications Research Laboratory and the Japan Aerospace Exploration Agency, and can carry out fully polarimetric observation at both X-band and L-band. However, we use only X-band data in this paper. The polarimetric calibration of this data was conducted using Quegan's method. Figure 1 shows the HH polarization 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 window 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 average indices ($\text{Cor}(S_{RR}, S_{LL})$, $\text{Cor}(S_{HH}, S_{HV})$ and $\text{Cor}(S_{HV}, S_{VV})$) of each test area. The result is shown in Fig.2. In sea area, the index in RL basis, $\text{Cor}(S_{RR}, S_{LL})$, is about 0.9 and the indices in HV basis, $\text{Cor}(S_{HH}, S_{HV})$ and $\text{Cor}(S_{HV}, S_{VV})$, 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 causes the double-bounce scattering which satisfies the simple scattering model of eq.(8). 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. Therefore, ρ of eq.(8) 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 3 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 proposed indices of polarimetric correlation coefficients are useful to discriminate between the vegetation area and urban area. Moreover, in order to separate sea area and residential area in Fig.3 (c), it seems that the RCS (Radar cross section) becomes useful index.

5. Conclusion

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

References

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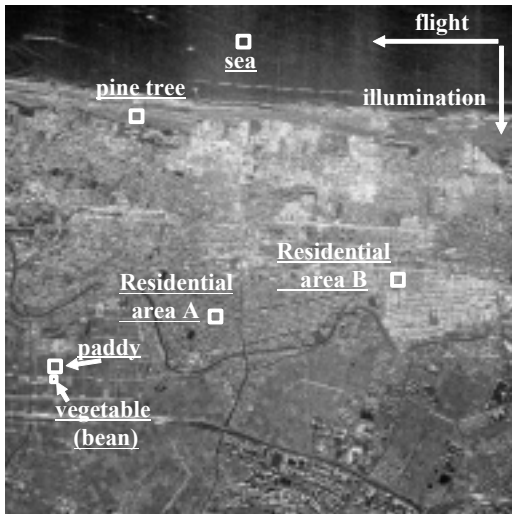


Fig.1 The HH polarization SAR image in Kobari area.

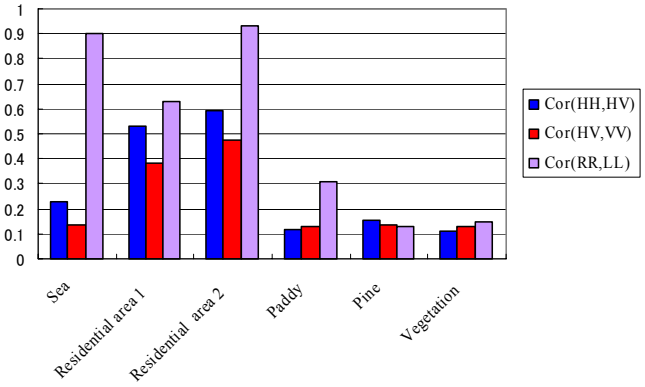


Fig.2 The comparison of three average Indices of polarimetric correlation Coefficient for each test area.



(a) Cor(HH,HV)



(b) Cor(HV,VV)



(c) Cor(RR,LL)

Fig.3 The image of three indices in Kobari area.
 (a) Cor(HH,HV), (b) Cor(HV,VV),
 (c) Cor(RR,LL)