

## PAPER

# Classification of Terrain by Implementing the Correlation Coefficient in the Circular Polarization Basis Using X-Band POLSAR Data

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**SUMMARY** Classification of terrain is one of the most important applications of Polarimetric Synthetic Aperture Radar (POLSAR) image analysis. This paper presents a simple method to classify terrain by the use of the correlation coefficients in the circular polarization basis together with the total power of the scattering matrix in the X-band. The reflection symmetry condition that the co-polarized and the cross-polarized correlations are close to zero for natural distributed scatterers is utilized to extract characteristic parameters of small forests or cluster of trees, and oriented urban building blocks with respect to the direction of the radar illumination. Both of these kinds of scatterers are difficult to identify in high resolution POLSAR images of complex urban areas. The indices employed here are the correlation coefficient, a modified coefficient normalized by the reflection symmetric conditional case, and the total power. It is shown that forest areas and oriented building blocks are easily detected and identified. The terrain classification yielded by these combinations is very accurate as confirmed by photographic ground truth images.

**key words:** radar polarimetry, polarimetric synthetic aperture radar (POLSAR), correlation coefficient, circular polarization basis, scattering power

## 1. Introduction

The Advanced Land Observing Satellite (ALOS) has been operating successfully in the space after its launch on Jan. 24, 2006. It is equipped with the L-band fully polarimetric data-take function. Although it is an experimental operational mode, it provides us with the first fully polarimetric data sets from space. In addition, the TerraSAR-X will be operating soon with the X-band polarimetric data acquisition mode, and the RadarSAT-2 will provide the C-band polarimetric data in the very near future. Therefore, a considerable data base of fully polarimetric data will become available to the remote sensing community in the near future for testing their algorithms.

Detection or classification of terrain is one of the most important applications of polarimetric radar remote sensing. In this regard, a lot of attention is paid to the utilization of fully polarimetric data sets. Various methods have been proposed for polarimetric data analysis [1]–[11];

and frequently used techniques are 1) entropy, angle alpha, anisotropy [1], [2] or total power concept [3], 2) the three- or four-component decomposition of scattering powers [4]–[7], and 3) the correlation coefficient method [8]–[11]. These approaches have successfully been incorporated into POLSAR image analysis.

However, it became clear that there exist two types of difficulties in detection or identification in urban area analyses of very high resolution POLSAR data. The first one is oriented buildings or oriented residential houses with respect to the radar illumination direction. This difficulty is caused by the small RCS (or equivalently total power) caused by edge diffraction compared to the large RCS by the double-bounce scattering from dihedral structures of orthogonal buildings, respectively. The cross-polarized component is rather large compared to the co-polarized components although the total power is small. This fact leads to miss-classification with respect to other scattering types such as small clusters of man-made structures. The second one is trees or tall vegetation in urban areas. Since trees or tall vegetations exhibit similar polarimetric scattering characteristics to those of oriented buildings, it becomes difficult to distinguish them.

If we apply the scattering power decomposition [7] to the complex urban scenario, oriented houses and trees are classified into one single volume (or diffuse) scattering structure (see Fig. 1). This is a problem in that POLSAR cannot distinguish these in the complex scenario by implementing only previous approaches. Therefore the purpose of the present paper is to classify these two scatterer types in urban areas distinctively in a simplified manner.

We present the correlation coefficient approach to distinguish these two scatterer types. It is known that the circular polarization correlation coefficient contains essential polarimetric indices and provides better performance in classification and detection of scattering structures [9]–[11]. A slight modification of the correlation coefficient taking into account the reflection symmetry condition enables us to detect man-made structures more easily. Since the total power is the most essential parameter in any radar system, a combination with the total power and the correlation coefficient, and its modification, leads us to classify terrain very effectively.

In Sect. 2, the detection problem for oriented buildings

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and houses is identified. A modification of the correlation coefficient normalized by the reflection symmetry case is provided. A simple method to extract clusters of trees is explained in Sect. 3. The classification algorithm is presented in Sect. 4. The classified result applied to X-band Pi-SAR data sets is shown in Sect. 5.

## 2. Detection of Oriented Buildings

In order to identify the problem of the oriented urban block detection, we first show in Fig. 1 a result of the three-component decomposition of the scattering powers. The image is based on the X-band high resolution (1.5 m by 1.5 m) fully polarimetric data sets acquired by the NiCT/JAXA airborne ‘‘Pi-SAR’’ system over Western Niigata, Japan. Color-code is used for indication of the scattering powers: Green (volume scattering) Red (double bounce scattering), and Blue (surface scattering), respectively. We can easily recognize that Red areas correspond to buildings or houses orthogonal to the radar illumination direction. On the other hand, Green areas surrounded by yellow circles are residential houses whose directions are oriented with respect to the radar illumination direction. The echo strength from the oriented residential area is small and these areas are classified into Green which also includes clusters of trees.

Although the scattering structures are similar houses, the detection result tends to change with changes of the radar illumination direction. They are classified into single volume scattering. If the total power is small, the corresponding area may be miss-classified into tree clusters within highly complex urban areas. This is not favorable for POLSAR image classification.

It is desirable to detect man-made structures against natural scatterers distinctively even though the man-made structures are oriented to the radar illumination. Up to now, two methods have been proposed to solve this problem by using: 1) the correlation coefficient in the HV polarization basis [10] and in the circular polarization basis [9], and 2) the modified version of correlation coefficient in the circular polarization basis [11]. We exploit the possibility of the correlation coefficient in the circular polarization basis for the discrimination.

### 2.1 Modified Correlation Coefficient

The correlation coefficient in the circular polarization (LR) basis can be written in terms of scattering elements as

$$\gamma_{LL-RR} = \frac{\langle 4|S_{HV}|^2 - |S_{HH} - S_{VV}|^2 \rangle - j4\text{Re} \langle S_{HV}^* (S_{HH} - S_{VV}) \rangle}{\sqrt{\langle |S_{HH} - S_{VV} + j2S_{HV}|^2 \rangle \langle |S_{HH} - S_{VV} - j2S_{HV}|^2 \rangle}} \quad (1)$$

$$\varphi_{LL-RR} = \tan^{-1} \frac{4\text{Re} \langle S_{HV}^* (S_{HH} - S_{VV}) \rangle}{\langle |S_{HH} - S_{VV}|^2 - 4|S_{HV}|^2 \rangle} \quad (2)$$

The symbol  $\langle \bullet \rangle$  denotes ensemble average. The phase information is used to extract terrain slopes [8], and man-made

structures [9].

In the reflection symmetry condition that the co-polarized and cross-polarized scattering correlations are close to zero [4]–[7], [12], the following characteristics hold for a natural distributed scatterer

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

Under this reflection symmetry condition (3), the correlation coefficient becomes real-valued and is expressed as

$$\gamma_{LL-RR}(0) = \frac{\langle 4|S_{HV}|^2 - |S_{HH} - S_{VV}|^2 \rangle}{\langle 4|S_{HV}|^2 + |S_{HH} - S_{VV}|^2 \rangle} \quad (4)$$

If we normalize (1) by (4)

$$\gamma'_{LL-RR} = \frac{|\gamma_{LL-RR}|}{\gamma_{LL-RR}(0)}, \quad (5)$$

this value will be close to unity for a reflection symmetry scatterer and larger than unity for the non-reflection symmetry case [11]. For discrimination of (1) versus (5), we denote (5) as a modified correlation coefficient.

### 2.2 Extraction of Oriented Urban Area by Modified Correlation Coefficient

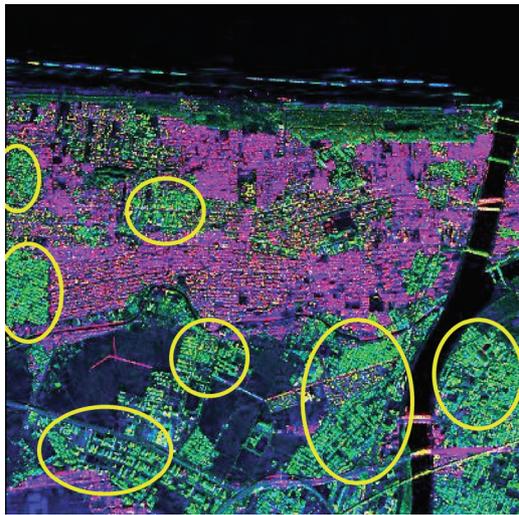
The values of (5) of specific scattering structures in Fig. 1 are shown in Table 1. It is seen that the oriented houses exhibit large values of more than 2 compared to other areas. Orthogonal urban areas exhibit values similar to those of the reflection symmetry scatterer. Therefore, it is possible to extract oriented urban blocks using the modified correlation coefficient only. The detection result by the modified correlation coefficient is shown in Fig. 2. It is seen that typical oriented residential houses are highlighted in the same circles in Fig. 1.

## 3. Tree Area Detection

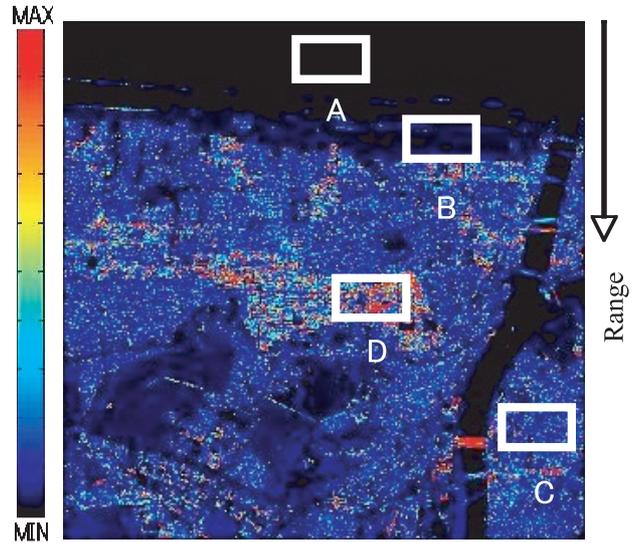
It is known that clusters of trees or forests exhibit volume or diffuse scattering characteristics having small total power. If trees are mixed within complex urban areas, the detection of trees becomes difficult because strong total powers from man-made structures mask the tree echo. Figure 3 shows the total power image of the same area.

If we examine the distribution of the correlation coefficient (1) for specific areas shown in a rectangular box in Fig. 3, the values exhibit specific features as shown in Fig. 4. Sea and forest areas are typical reflection symmetry scatterers. The mean value of the coefficient is close to  $-1$  for sea and  $0$  for the forest. The values of oriented urban areas are widely spread within the unit circle in the complex plane, while the mean values of orthogonal blocks are concentrated around  $-1$  on the plane. These characteristics are common to other data sets acquired with the X-band Pi-SAR.

If we pay attention to forest areas, the mean value is concentrated around  $0$ . This situation serves to extract



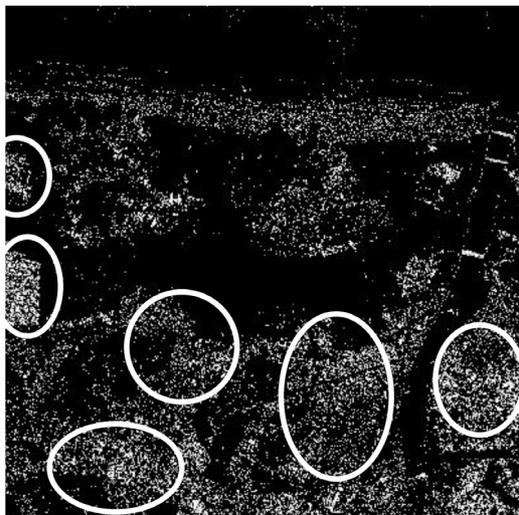
**Fig. 1** Three-component decomposition result of the scattering powers for Western Niigata, Japan, with Green (volume scattering), Red (double bounce scattering), Blue (surface scattering). Yellow circles indicate oriented residential areas.



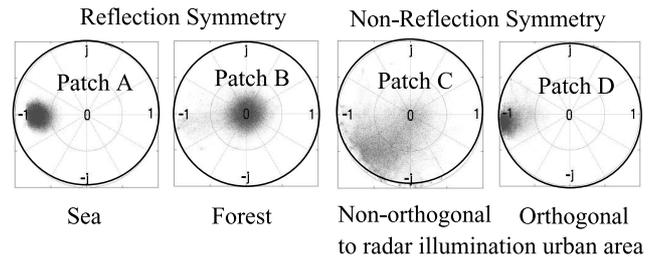
**Fig. 3** The total power image of Fig. 1 (X-band Pi-SAR data). Patch A: Sea, B: Forest, C: Urban area non-orthogonal to radar illumination, D: Urban area orthogonal to radar illumination.

**Table 1** Values of modified correlation coefficient.

Category	$\gamma'_{LL-RR}$
Non-orthogonal urban area	2.54
Orthogonal urban area	1.12
Forest (pine trees)	1.44
Crop field	1.22
Paddy rice field	1.11
Sea-shore	1.10
Sea	1.01



**Fig. 2** Detection result of oriented urban blocks.



**Fig. 4** The distribution of the correlation coefficient for specific areas in Fig. 3.

forested areas in a very simple way. If we take the reciprocal of (1),  $\frac{1}{|\gamma_{LL-RR}|}$ , the value becomes very large for the tree area or forested area, respectively.

Figure 5 shows the value of  $\frac{1}{|\gamma_{LL-RR}|}$  which indicates the tree or forested area in Fig. 3. For the sake of comparison, an aerial photo of the same area is shown in Fig. 6. The bright areas in Fig. 5 are in good agreement with trees in the actual photo image. As can be deduced, it is possible to identify small forests along seashore and cluster of trees in urban residential area. They are perfect matches between Fig. 5 and Fig. 6.

#### 4. Classification of Terrain by Total Power and the Correlation Coefficients

Since the total power is the essential radar parameter and the correlation coefficient in the circular polarization basis provides useful information, it is possible to use these parameters for identification and classification of complex urban terrain. We propose here to use the following algorithm for classification as shown in Fig. 7. The algorithm consists of the total power and the correlation coefficient and its modification in Sect. 2. The total power below  $-13$  dB is assigned

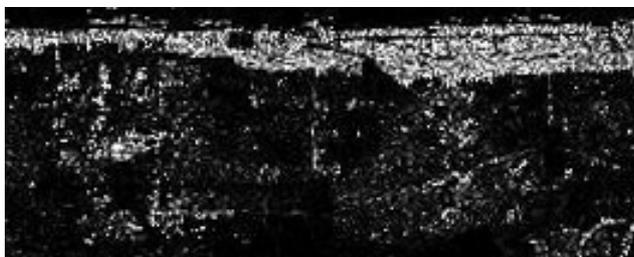


Fig. 5 Tree clusters highlighted by  $\frac{1}{|\gamma_{LL-RR}|}$ .



Fig. 6 An aerial photo image of the area.

to sea or water area for exclusion of spiky noise in that area even if  $|\gamma_{LL-RR}|$  is large. The total power larger than  $-5.2$  dB with  $|\gamma_{LL-RR}| > 0.6$  is assigned to orthogonal urban scatterer (orthogonal to radar illumination), because the magnitudes of the total power and the correlation coefficient are large for man-made structures (see Fig. 3 and Fig. 4, respectively). In the range of  $-13 < TP < -5.2$  dB, the appropriate values of the correlation coefficients  $|\gamma_{LL-RR}|$  and the modified  $|\gamma'_{LL-RR}|$  are employed to discriminate areas based on Table 1 and Fig. 4. Since the radiometric and polarimetric calibrations have been carried out in the Pi-SAR data sets, these criterion values can be applied to other scenes. A slight change in the criterion values can be acceptable, in case that the same area is covered with snow.

As can be seen, the algorithm is quite simple.

### 5. Discussion

Figure 8 shows the classified result by the algorithm. Color-bars are used for indicating corresponding regions. Green areas are determined mainly by  $\frac{1}{|\gamma_{LL-RR}|}$ . The oriented urban area is derived by the modified correlation coefficient and is colored Yellow. The averaging widow size is 10 by 10 pixels. It is seen that the classified results are in quite good agreement with the actual photo ground truth data. The oriented residential area is discriminated from forest, which has not been possible in the three-component scattering power decomposition image.

### 6. Concluding Remarks

A simpler method to extract clusters of trees and oriented residential blocks in highly complex urban areas is proposed. The indices employed here are the correlation co-

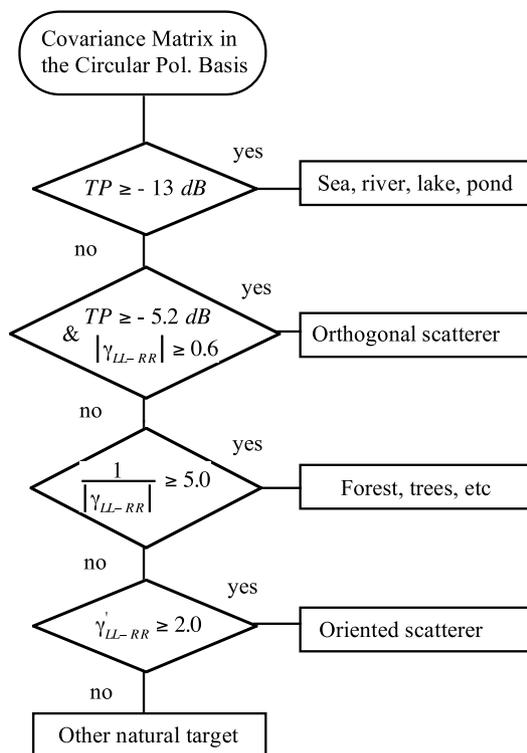


Fig. 7 Classification algorithm for complex urban area.

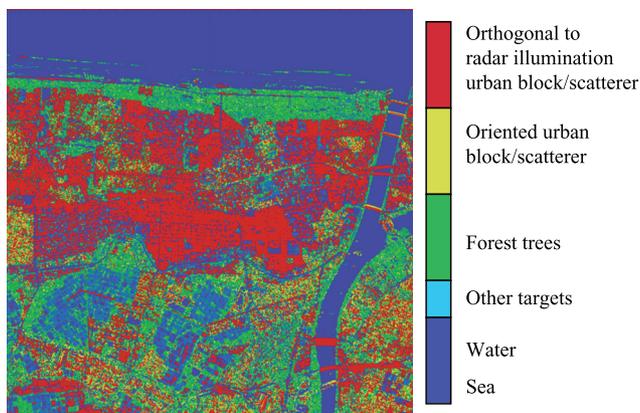


Fig. 8 Classified image of Western Niigata, Japan.

efficient, a modified coefficient normalized by the reflection symmetric condition case, and the total power. It is shown that clusters of trees and oriented building blocks are easily discriminated and identified. The results of classification by these indices are in good agreement with the photo ground truth.

For further development to the other frequency band data, it is necessary to find out suitable indices. For example, the distribution of the correlation coefficient for tree areas is concentrated around zero in the complex plane for this X-band data. This concentration is the main source of the present method. For the L-band data, the concentration is not so dense. Therefore, another index which leads to some concentration on a specific portion in the complex plane is

important.

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