A PolSAR Classification Method Based on Scattering Model and Polarization Correlation Coefficient

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Abstract— Recently, many PolSAR image classification methods have been proposed. One commonly used method is based on the scattering model. However, traditional classification based on scattering model usually overestimates the volume scattering contributions, especially in urban areas, resulting in buildings not orthogonal to radar Line-Of-Sight (LOS) misjudged as forests. To solve this problem, an improved PolSAR classification method based on scattering model and polarization correlation coefficient is presented in this paper. By introducing two types of polarization correlation coefficients, circular-pol correlation coefficient (CCC) and normalized circular-pol correlation coefficient (NCCC), the oriented buildings can be effectively extracted from the volume scattering. Since the amplitude values of CCC of forests are very small, while that of buildings orthogonal to radar LOS or with small orientation angles are close to 1. Therefore, the CCC parameter is firstly used to extract some slightly tilted oriented buildings form the initial volume scattering category. Then, the NCCC parameter is introduced to distinguish the buildings with large orientation angles from the remainder volume scattering components. Since these buildings hold strong non-reflection symmetry and larger orientation angles, the values of NCCC of this kind are much larger than that of forests. Finally, the extracted buildings are reclassified into a new oriented buildings category. In order to maintain the dominant scattering mechanism characteristics, the classification method preserving scattering characteristics is utilized to classify the corrected scattering categories. The proposed classification algorithm remedies the defect of traditional scattering-model-based classification method and the experiment result of an E-SAR L-band PolSAR image of Oberpfaffenhofen, Germany demonstrates the effectiveness of the proposed method.

1. INTRODUCTION

Terrain classification has become one of the most important applications for polarimetric synthetic aperture radar (PolSAR) image. Among various classification methods, the method utilizing targets scattering mechanisms model is a hot topic [1]. To maintain targets polarimetric scattering characteristics, Lee et al. [2] developed a classification method comprised of three-component scattering model and wishart classifier. This method preserves the purity of scattering categories in classification procedures, which greatly improves the result of the classification based on scattering model. By now, the scattering-model-based decomposition is the primary approach to get scattering mechanism information of targets. However, a known issue of this decomposition is the overestimation of volume scattering power, especially in urban areas [3]. Traditional scattering-model-based decompositions usually assume that man-made structures corresponds to double-bounce scattering and only volume scattering contributes to the cross-polarization term. As we know, buildings aligned facing the radar look direction satisfy the reflection symmetry and produce high double-bounce scattering power. Nevertheless, the oriented buildings whose walls are not orthogonal to radar LOS do not satisfy the reflection symmetry. These buildings will introduce cross-polarization power, resulting in these buildings misjudged as forest.

In order to eliminate the classification confusion, an improved PolSAR image classification method based on scattering model and polarization correlation coefficient is presented in this paper. It is known that the circular-pol correlation coefficient (CCC) and the normalized circular-pol correlation coefficient (NCCC) contain essential polarimetric information and have good performances on terrain classification and detection of targets. By introducing the two parameters in classification based on scattering model, the oriented buildings can be successfully distinguished from forest areas. A DLR E-SAR L-band quad-polarized SAR image of Oberpfaffenhofen, Germany is used to verify the effectiveness of the proposed method.

2. BACKGROUND AND THEORY

In this section, we give a brief review of the four-component model-based decomposition and two polarization correlation coefficients.

2.1. Four-component Model-based Decomposition

In order to accommodate the decomposition scheme for the more general scattering case, Yamaguchi proposed a four-component scattering model. Based on the Freeman and Durden decomposition, the decomposition model introduces an additional helix scattering corresponding to non-reflection symmetric cases [4]. Four-component decomposition with coherence matrix can be written as

$$\langle [T] \rangle = f_s \langle [T] \rangle_s + f_d \langle [T] \rangle_d + f_v \langle [T] \rangle_v + f_C \langle [T] \rangle_c \tag{1}$$

where f_s, f_d, f_v and f_c are the coefficients to be determined. $\langle [T] \rangle_s$, $\langle [T] \rangle_d$, $\langle [T] \rangle_v$, $\langle [T] \rangle_c$ are expansion matrices corresponding to the surface, double-bounce, volume and helix scattering mechanisms, respectively. According to the decomposition algorithm, the total scattering power can be successfully decomposed into four scattering components, Ps, Pd, Pv and Pc.

2.2. The Circular-pol Correlation Coefficient (CCC)

The circular-pol correlation coefficient can be expressed as

$$\rho_{RR-LL} = \frac{\langle S_{RR} S_{LL}^* \rangle}{\sqrt{\langle S_{RR} S_{RR}^* \rangle \langle S_{LL} S_{LL}^* \rangle}} = \frac{\left\langle 4 |S_{HV}|^2 - |S_{HH} - S_{VV}|^2 \right\rangle - i4Re \langle S_{HV}^* (S_{HH} - S_{VV}) \rangle}{\sqrt{\left\langle |S_{HH} - S_{VV} + i2S_{HV}|^2 \right\rangle \left\langle |S_{HH} - S_{VV} - i2S_{HV}|^2 \right\rangle}} \tag{2}$$

Schuler et al. [5] indicate that $|\rho_{RR-LL}|$ is related to the surface roughness and man-made structures. For low surface roughness bare land, the value is relatively large, while for other natural distributed targets such as forests, $|\rho_{RR-LL}|$ is very low. In addition, when radar illumination direction is orthogonal to the alignment of the buildings, $|\rho_{RR-LL}|$ tends to be unity, whereas for oblique illumination case, it becomes smaller with the increasing of building orientation angle [6]. Therefore, CCC can be utilized to distinguish the slightly tilted oriented buildings.

2.3. The Normalized Circular-pol Correlation Coefficient (NCCC)

In order to reduce the effects of scattering terms that are associated with natural areas and simultaneously to enhance the return from man-made structures, Ainsworth et al. [7] introduce a parameter, the normalized circular-pol correlation coefficient (NCCC), which can be written as

$$\rho'_{RR-LL} = \left| \frac{\rho_{RR-LL}}{\rho_{RR-LL}(0)} \right| = \sqrt{\frac{1 + \tan^2(4\theta)}{1 - \tau^2}} \tag{3}$$

where θ is orientation angle, and τ is helicity indictor. $\rho_{RR-LL}(0)$ is the normalization term, under the reflection symmetry $\langle S_{HV} S_{HH}^* \rangle \approx \langle S_{HV} S_{VV}^* \rangle \approx 0$. And it can be straightforwardly derived from Eq. (2) as

$$\rho_{RR-LL}(0) = \frac{\left\langle 4 |S_{HV}|^2 - |S_{HH} - S_{VV}|^2 \right\rangle}{\left\langle 4 |S_{HV}|^2 + |S_{HH} - S_{VV}|^2 \right\rangle} \tag{4}$$

With the normalization processing, the NCCC will be close to unity for reflection symmetry scatterers and larger than unity for the non-reflection symmetry case. So NCCC is considered as a useful polarimetric indicator for distinguishing oriented buildings with large orientation angles from volume scattering.

3. METHOD

In order to reduce the classification confusion between oriented buildings and the volume scattering category, we propose an improved classification method based on four-component scattering model and the two parameters, CCC and NCCC. The flow chart of the proposed method is shown in Figure 1. Detailed steps are as follows.

3.1. Four-component Decomposition and Initial Classification

Apply four-component decomposition to PolSAR data, then divide pixels into surface, double-bounce and volume scattering categories, based on the maximum power of the three scattering mechanisms (the helix category is ignored).

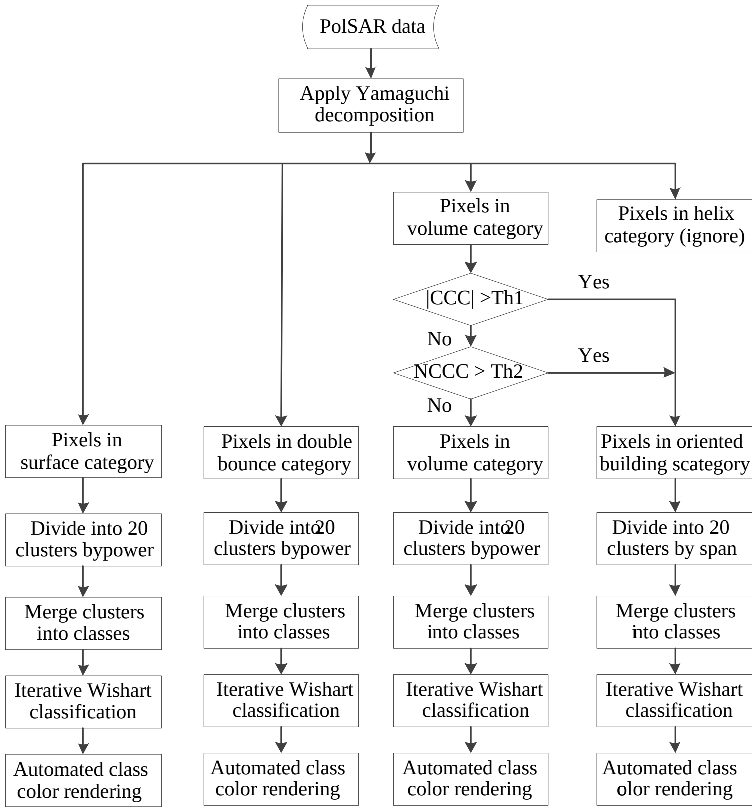
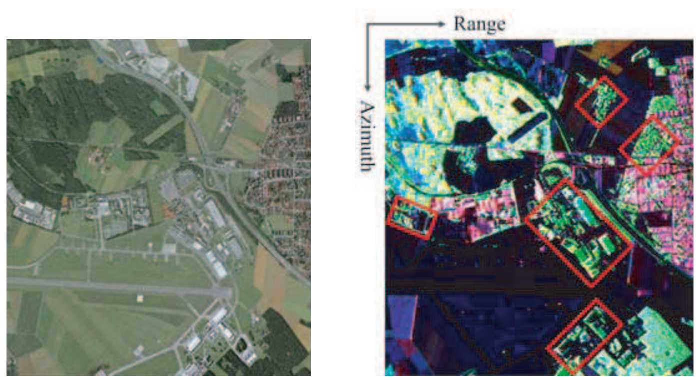


Figure 1: The flow chart of the proposed classification method.



(a) (b)

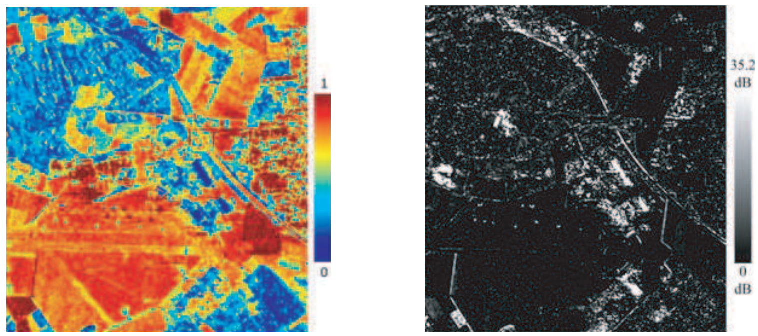
Figure 2: (a) Optical image. (b) Four-component decomposition result.

3.2. Scattering Categories Rectification

Calculate the amplitude of CCC (|CCC|) and NCCC, respectively. In order to distinguish the oriented buildings, set two reasonable corresponding thresholds Th1 and Th2. For each pixel belong to volume scattering category, if the |CCC| is larger than Th1 or less than Th1 but with NCCC larger than Th2, reclassify it into a new oriented buildings category, otherwise remain its volume scattering category unchanged.

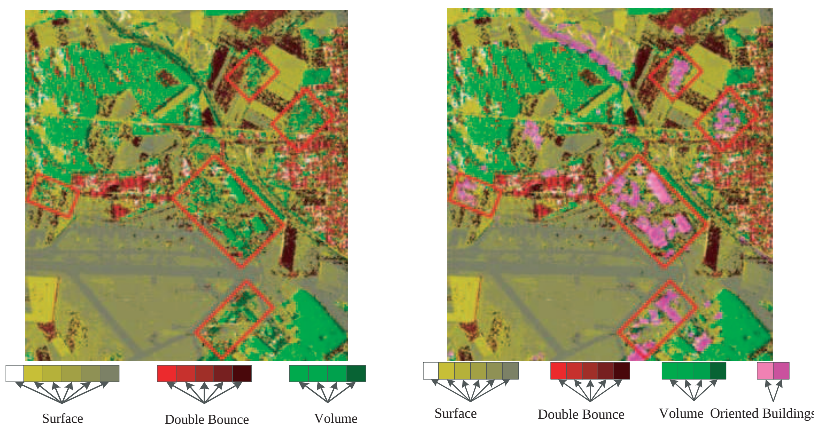
3.3. Classification with Wishart Classifier

For the surface, double-bounce and rectified volume categories, they are finely classified into small clusters according to the dominated scattering mechanism powers. While the extracted oriented buildings category is finely classified according to the total scattering power. Then apply the classification method preserving polarimetric scattering characteristics [2]. The procedures mainly include fine clusters partition, cluster merging, iterative Wishart classification and automated color rendering.



(a) (b)

Figure 3: ((a) The amplitude of CCC. (b) The logarithmic graph of NCCC.



(a) (b)

Figure 4: Classification results. (a) Traditional method. (b) The proposed method.

4. RESULTS AND DISCUSSIONS

A DLR E-SAR L-band full polarized image is used to demonstrate the effectiveness of the proposed method. The data is acquired over Oberpfaffenhofen, Germany. The image contains 1300×1200 pixels and its spatial resolution is $3\,\mathrm{m} \times 3\,\mathrm{m}$. The corresponding optical image is shown in Figure 2(a). There exist forest, lawns, farmland, and buildings with different orientation angles in the imagery.

In order to illustrate the influence of building alignment direction, we show in Figure 2(b) a result of the four-component decomposition. Color-code is used for indication of the scattering powers: Red (double-bounce scattering), Green (volume scattering), and Blue (surface scattering), respectively. It can be easily observed that buildings facing the radar look direction present double-bounce scattering characteristic, while the oriented buildings not orthogonal to radar LOS shown in red rectangular regions are dominated by volume scattering mechanism. To analysis the performance of oriented buildings on two polarization correlation coefficients, the amplitude of CCC, |CCC|, and the logarithmic graph of NCCC are shown in Figures 3(a) and (b). It can be seen that some slightly tilted oriented buildings also have relatively large |CCC|, besides the buildings facing the radar look direction. And those buildings with orientation angles around $\pm 45°$ have larger NCCC than forest areas. Therefore, two appropriate thresholds can be set to extract the oriented buildings from the volume scattering. As for the PolSAR data used in this paper, two reasonable thresholds, Th1 and Th2, are set to 0.65 and 0.35 respectively.

Then by applying the proposed classification method, an improved classification result is shown in Figure 4(b). For better comparison, Figure 4(a) presents the traditional classification result. It can be observed that these oriented buildings in the red rectangular regions are effectively distinguished from volume scattering. In addition, surface and double-bounce classes remain their scattering characteristics unchanged, which well preserves the advantage of the traditional classification method for these targets.

5. CONCLUSIONS

This paper proposed an improved PolSAR image classification method based on scattering model and polarization correlation coefficient. In order to solve the classification confusion between oriented buildings and forests, the proposed method introduces two polarization correlation coefficients, circular-pol correlation coefficient and normalized circular-pol correlation coefficient. According to the different performance of oriented buildings and forests on the two parameters, two reasonable thresholds are set to distinguish the two kinds. The proposed method effectively weakens the scattering mechanism ambiguity and remedies the defect of traditional scattering-model-based classification method. The experiment result of an E-SAR L-band PolSAR image of Oberpfaffenhofen, Germany demonstrates the effectiveness of the method for terrain classification.

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