Urban Building Change Detection Based on Improved Four-component Scattering Model

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Abstract. A four-component scattering model and the enhanced double-bounce scattering with the rotation of coherency matrix was previously studied, and on this basis, a method for improving Polarimetric Synthetic Aperture Radar (PolSAR) to precisely detect urban buildings is proposed. To this end, Helix scattering and enhanced double-bounce scattering components are combined to detect the urban building change. Application of the RADARSAT-2 polarimetric data of August 9, 2008 and May 24, 2009 to the reconstruction of Mianzhu City, Sichuan Province, China, and experimental results show that the improved model is feasible and effective for improving the accuracy of detecting changes in city buildings.

1. Introduction
SAR is independent of daytime and clouds cannot obstruct its view, ensuring continuous supply of information with every pass even under unfavorable weather conditions, and it is suitable for building detection in urban areas. PolSAR is used to obtain the complex scattering matrix, which is a complete description of the electromagnetic scattering phenomena. Therefore, this matrix can accurately detect target characteristics with the advantages of traditional SAR. PolSAR can acquire echo responses of ground objects to radar signals of different wavebands. Compared with the traditional single PolSAR, the outstanding advantages of PolSAR images lie in that the measurement data contain more abundant target information, enabling more accurate target detection and classification, and providing the possibility for information mining [1].

Many studies show that when flight direction of PolSAR is different, the same building has distinct characteristics in the radar images [2-4]. Because of the different directions, urban buildings show different backscattering; this phenomenon makes the results of urban building extraction problematic and unsatisfactory. In order to increase the accuracy of urban building detection and classification from PolSAR data, the Yamaguchi four-component decomposition scattering model was taken into account. When buildings are parallel to the flight direction of the radar, the signal intensity of the buildings is more than that of the surrounding objects [5], and the three-component and four-component scattering models can be used to detect this type of buildings by obtaining the double-bounce scattering signals between the wall and the ground. However, the strong double-bounce scattering angle reflection is less than 10° [6]. When there is a large angle between radar flight direction and buildings, the double-bounce scattering is not satisfactory. Considering the above mentioned factors, this paper presents a method that combines the spiral volume scattering component of the Yamaguchi four-component scattering model with the dihedral scattering component enhanced by the coherent rotation matrix to detect urban buildings.
2. Study area and datasets
In order to verify the effectiveness of the proposed method, Mianzhu City, Sichuan Province, China was selected as a test area. The city is located in the northwest of Sichuan Basin (east longitude 103° 54’ – 104° 20’, north latitude 30° 09’ – 31° 42’), and wavy terrain is very small. Urban area is 11.86 square kilometers including Jiannan Town, Southwest Town, Northeast Town, and Xiaode Town.

The main image sensors of RADARSAT-2 are C-band SAR with multiple imaging modes, which adopts full polarization (HH/HV/VH/VV) work mode. These sensors can significantly increase the number of detectable objects or target category, providing radar data with 3-100 m resolution and 10-500 km width. The main imaging mode can provide a strip image with a sample of 3 m each. The data used in this study is the SLC format data (ground range, unsigned 16-bit integer number, 8-m pixel spacing) from August 9, 2008 for the test site.

3. Urban Building Change Detection
3.1. Yamaguchi Decomposition Model
The coherent matrix based on the Yamaguchi four-component scattering power decomposition model can be extended to [7]:

\[
\langle |T| \rangle = f_s \langle |T| \rangle_{surf} + f_d \langle |T| \rangle_{double} + f_v \langle |T| \rangle_{vol} + f_c \langle |T| \rangle_{helix}
\]  

where \( f_s, f_d, f_v, \) and \( f_c \) are surface scattering, double-bounce scattering, volume scattering, and helix scattering components, respectively. Thus, we can obtain \( p_s \) (surface scattering), \( p_d \) (double-bounce scattering), \( p_v \) (volume scattering), and \( p_c \) (helix scattering) components of the power by the following formula:

\[
(p_s = f_s (1 + |\alpha|^2), \quad p_d = f_d (1 + |\beta|^2), \quad p_v = f_v, \quad p_c = f_c)
\]

Through this model, the double-bounce scattering component has been widely applied to the detection of non-natural objects or buildings [8], but when the angle between the flight direction of radar and buildings is relatively large, the detection rate is reduced. The helix scattering power is related to \( S_{hh} S_{vv}^* \) or the imaginary part of \( S_{hv} S_{hv}^* \), which is often used in complex urban areas. In a complex urban area, the reflection symmetry, \( S_{hh} S_{hv}^* = 0 \) or \( S_{hv} S_{vv}^* = 0 \), condition is often not satisfied. For example, when the angle between the flight direction of radar and buildings is relatively large, \( S_{hh} S_{hv}^* \neq 0 \) or \( S_{hv} S_{vv}^* \neq 0 \), the helix scattering component can be used to detect non-natural targets.

3.2. Enhanced Double-bounce Scattering
As mentioned above, when there is a large angle between radar flight direction and buildings, the double-bounce scattering component does not work for non-natural targets. Therefore, the orientation angle needs to be standardized [9], that is, the coherent rotation matrix will effectively enhance the double-bounce scattering power [10].

Assume the following coherent matrix:

\[
\langle |T| \rangle = \begin{bmatrix}
T_{11} & T_{12} & T_{13} \\
T_{21} & T_{22} & T_{23} \\
T_{31} & T_{32} & T_{33}
\end{bmatrix}
\]
The coherent matrix can be obtained after rotating $\theta$ angle:
\[
\begin{bmatrix}
T_{11}(\theta) & T_{12}(\theta) & T_{13}(\theta) \\
T_{21}(\theta) & T_{22}(\theta) & T_{23}(\theta) \\
T_{31}(\theta) & T_{32}(\theta) & T_{33}(\theta)
\end{bmatrix}
\]
where the rotation matrix is:
\[
\begin{bmatrix}
1 & 0 & 0 \\
0 & \cos 2\theta & \sin 2\theta \\
0 & -\sin 2\theta & \cos 2\theta
\end{bmatrix}
\]
Therefore, the rotation $\theta$ angle is:
\[
\theta = \frac{1}{4} \tan^{-1} \left( \frac{4\Re(S^\ast_{uv}(S_{HH} - S_{VV})}{\left| S_{HH} - S_{VV} \right|^2 - 4\left| S_{uv} \right|^2} \right)
\]
In short, the basic steps for the enhancement of the double-bounce scattering component are as follows:
1) Estimate the offset of the direction angle.
2) Compensate the offset of the direction angle.

### 3.3. Urban Building Change Detection

Therefore, the enhanced double-bounce scattering component is effective for small angles between the flight direction and urban buildings, and the helix scattering component is effective for the large angles between the flight direction and urban buildings. Therefore, the double-bounce and helix scattering components can be combined to effectively detect changes in urban buildings; the flow chart is shown in Figure 1.
Figure 1. Flow chart of urban building detection

Figure 2. Scattering model decomposition in the study area on May 24, 2009  (a) Double-bounce scattering (b) Enhanced double-bounce scattering  (c) Helix scattering

Figure 2 shows the double-bounce, enhanced double-bounce, and helix scattering components obtained by the improved Yamaguchi four-component scattering model for full polarimetric data of RADARSAT-2 on May 24, 2009 in Mianzhu City. White areas in Figure 2 (a) show the strong double-bounce scattering produced by non-natural objects perpendicular to the flight direction. The directions of most buildings in most areas in the red circles are not perpendicular to the flight direction, so the double-bounce scattering component cannot effectively recognize non-natural objects. Comparing Figure 2 (b) and Figure 2 (a), it can be seen that most areas in the red circles, after the enhancement of the coherent rotation matrix, the angles between the flight direction and the buildings are less than or equal to 45° [11]. This implies that the double-bounce scattering component of non-natural objects was significantly enhanced. The angles between the non-natural objects and the flight direction in the areas in the red circles in Figure 2 (c) are large, and the helix scattering component is larger. Therefore, the enhanced double-bounce scattering and helix scattering are complementary, and the enhanced double-bounce scattering and helix scattering were combined to feasibly and effectively detect non-natural objects.

4. Results and Analysis

Figure 3 shows RGB composite images based on the improved Yamaguchi four-component scattering model of August 9, 2008 and May 24, 2009 for Mianzhu City from RADARSAT-2 data. Green areas represent strong double-bounce scattering caused by non-natural objects. The upper right corner in Figure 3 (a) shows the temporary shelters built after the Wenchuan earthquake. Surrounding areas of
Mianzhu City are agricultural areas, in May, the main crops were wheat and rape, and in August, the main crops were rice and soybeans. The surface scattering was mainly caused by the crops in the fields. It can be seen from the comparison of Figure 3 (a) and Figure 3 (b) : a large number of non-natural objects in the city have changed. In order to further verify the experimental results, on-site survey was carried out on November 13, 2010, and two major changes were observed in the city proper: 1) most of the temporary shelters were demolished; and 2) reconstruction was basically complete.

![Figure 3. RGB composite images of the study area (a) August 9, 2008 (b) May 24, 2009](image)

Change map of the topographic features of Mianzhu City for August 9, 2008 and May 24, 2009 based on the improved Yamaguchi four-component scattering decomposition model shown in Figure 4. Red areas show the presence of non-natural objects and green areas represent the absence of non-natural objects. Changes in the double-bounce scattering were mainly due to the post-disaster reconstruction, and some temporary houses were removed, and some new non-natural objects were reconstructed, and some vegetation was planted simultaneously. In farmland areas, changes in the green areas are due to the changes in the type of crops. The results of the experiments are consistent with our on-site survey and the high-resolution optical remote-sensing images. In order to further verify the accuracy of the proposed method in change detection, typical non-natural objects and crops were verified using high-resolution optical remote-sensing images and on-site survey. The statistical analysis showed that the correct rate of change detection of non-natural objects was about 78.8% and the correct rate of the detected unchanged non-natural objects was about 74.9%.

![Figure 4. Change map of non-natural targets based on the improved Yamaguchi model](image)
5. Conclusion
This paper proposes a new method for improving the accuracy of urban building detection based on the Yamaguchi decomposition model. The required rotation angle for enhancing the double-bounce scattering component could be determined by minimizing the cross-polarization component, and the double-bounce scattering component could be enhanced using the rotation method of the coherent matrix. Then, the helix scattering component and the enhanced double-bounce scattering component were combined for application to the detection of changes in urban buildings. The comparison of the detected changes using the full polarimetric RADARSAT-2 data and the corrected data for Mianzhu City, Sichuan Province, China showed the effectiveness of the proposed method in improving the accuracy of the detection of urban building changes. At the same time, it also provides a methodological support for detecting changes in urban buildings.

6. References
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