Building extraction from GF-3 images using Wishart classification assisted by extended volume scattering model

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Abstract: Building extraction is considered as one of the primary applications of urban remote-sensing. To address the misclassification issue on building extraction based on Yamaguchi decomposition, an extended volume scattering model-assisted building extraction method is proposed. Here, the HV components caused by buildings whose main surface are oriented with respect to radar beam are assigned to double bounce scattering, since the extended volume scattering model is introduced. On this basis, the complex Wishart iterative classification is introduced to develop a new method of building extraction. The proposed method is employed to process C-band full-polarimetric SAR imagery obtained by GF-3. The study results verify the efficiency and accuracy of proposed method.

1 Introduction
Polarimetric SAR (PolSAR) images are increasingly used in building extraction, since its rich polarisation information are more conducive to classification and extraction of features. The existing methods for building extraction from PolSAR images are mostly based on polarimetric properties of buildings, and incoherent target decomposition based on physical models becomes the current research hotspot [1]. On this basis, buildings and vegetation are classified as double bounce scattering and volume scattering, respectively, and it is considered that the cross-polarisation component (HV) is the main source of volume scattering [2]. However, once the direction of buildings is not perpendicular to that of the radar line of sight, the cross-polarised component will be increased in the echo of oriented buildings and be identified as volume scattering [3–5]. At this point, there are not only vegetation but also buildings in the volume-scattering components.

In the aspect of physical model improvement, Yamaguchi et al. [2] use the rotating coherence matrix to perform oriented angle compensation (OAC) on the basis of traditional four-component decomposition to improve the overestimation of volume scattering. Sato [3] proposes a new extended volume scattering model based on dipole and dihedral angle scattering structures to reduce the volume scattering component. Yan Lili [1] reduces the negative mechanism is directly used to extract buildings from polarisation decomposed images. The coherency matrix after OAC based on the Yamaguchi four-component decomposition. Singh [4, 6] transforms the rotated coherence matrix to reduce the T23 component to 0, which improves the problem that all parameters are not fully utilised in the coherent matrix.

To sum up, this paper proposes a building extraction method using Wishart classification assisted by extended volume scattering model: First, OAC is performed after polarisation coherence matrix pre-processing. Then, each scattering component will be obtained based on the extended body scattering model using incoherent decomposition. Later, the building extraction results will be obtained by the Wishart classification performed on each scattering component. Finally, the experimental results of full-polarisation GF-3 SAR data show that the proposed method is effective.

2 Building extraction method

2.1 Building scattering properties
Comparing with the surface scattering and volume scattering manifested by water and vegetation, buildings often exhibit double bounce scattering. The main structural structures include walls and roofs. From the perspective of scattering characteristics, regardless of the direction in which the radar wave is radiated from, the backscattered echoes of the wall, roof, and ground are always mixed together, forming a bright overlay on SAR images. In addition, components such as metals built on buildings show prominent cross-side lobes on high-resolution SAR images.

2.2 Incoherent decomposition based on extended volume scattering model
Since non-coherent target decomposition is performed on urban areas with complex features, helix scattering needs to be considered. Therefore, the Yamaguchi four-component decomposition method that considers surface scattering, double-bounce scattering, volume scattering, and helix scattering is selected. In the Yamaguchi four-component decomposition method, buildings mainly exhibit double-bounce scattering. Whereas buildings with a certain angle between the main construction line and the radar line of sight tend to generate cross-polarisation components when interacting with polarised waves. It is considered to be a source of volume scattering, and therefore, before being decomposed, the polarisation coherence matrix needs to be compensated by the polarisation-oriented angle to reduce the distribution of such cross-polarisation components as volume scattering.

There are still mixed vegetation and oriented buildings in the volume scattering region after OAC, which is due to the volume scattering model used when cross-polarisation components are assigned. Considering randomly oriented dipole scatters and dihedral angle scattering, the extended volume scattering model proposed by Salto redistributes cross-polarised components in the case of Re{(S_{HH}S_{VV})} < 0.

2.3 Building extraction using Wishart classification assisted by extended volume scattering model
Since the distribution of man-made targets in urban areas is complex, when the classification method based on the scattering mechanism is directly used to extract buildings from polarisation decomposition results, the results are often limited. The Wishart unsupervised classification method based on scattering mechanism has the advantages of small initialisation influence, good convergence, and maintenance of pixel scattering type.
3 Experiment and result analysis

3.1 Figures incoherent decomposition based on extended volume scattering model

The proposed method was validated by full-polarimetric GF-3 SAR data with C-band in Chengdu in December 27, 2017. The image size is 1812 pixels × 2362 pixels, and the spatial resolution is 8m × 8 m. The area mainly includes buildings, forests, roads, rivers, green areas, and other types of objects. Optical images and SPAN are shown in Fig. 1. The scattering matrix was suppressed by speckle noise based on the spherical invariant random vector model before polarisation decomposition and OAC.

To illustrate the effect of the extended volume scattering model on the distribution of data in each channel of the scattering matrix and the effect on building characterisation, the following tests were designed: (1) Yamaguchi polarimetric decomposition with traditional model; (2) Yamaguchi polarimetric decomposition with OAC; and (3) Yamaguchi polarimetric decomposition with extended volume scattering model. After logarithmic stretching of double-bounce scattering, volume scattering, and surface scattering obtained after decomposition, the red, green, and blue colours are, respectively, assigned to the RGB synthesis maps, as shown in Fig. 2. The red box in Fig. 2a is buildings.

As reflected in Fig. 3, after the original Yamaguchi was decomposed, red tone appeared in the part of the building area, and part of it showed green tone. In Fig. 2c, the green trend in the building area has decreased, and the red and white tone have increased. It shows that in the building area, the volume scattering component obtained by polarisation decomposition is reduced, the double-bounce scattered component is increased, and the pixels with dominant volume scattering components do not dominate. That is, after the OAC, the cross-polarisation component of the building area is reduced. In Fig. 2c, the green tone of the building area is further weakened, and the red tone area is significantly enhanced. It shows that after the Yamaguchi decomposition based on extended volume scattering model, the cross-polarised components assigned to the volume scattering are greatly weakened, and the double-bounce scattering dominant of the oriented building area is significantly improved. In order to verify the above phenomenon and analysis, the power profile of parallel buildings and oriented buildings shown in red short lines 1 and 2 in Fig. 2a is extracted, as shown in Figs. 3 and 4.

For parallel buildings, three methods all have good reservations for double-bounce scattering of parallel buildings. For oriented buildings, Yamaguchi's traditional scattering model obviously overestimates the volume scattering component of the region. After OAC, the volume scattering component is suppressed, but the degree of suppression is not enough after the introduction of the extended volume scattering model, the volume scattering component is effectively suppressed and is significantly lower than the double-bounce scattering.

3.2 Building extraction

In order to compare the efficiency of proposed method, buildings are extracted by Yamaguchi–Wishart and proposed method called EV–Wishart. The building extraction results are shown in Fig. 5. Some reference samples for quantitative evaluation, marked in the ground truth map, the blue buildings samples and yellow non-buildings ones are listed in Table 1. Two regions, chosen from Fig. 5 to show the details of results, are shown in Figs. 6 and 7. The overall accuracy, the building omission rate, and the non-building omission rate are shown in Table 2.

As reflected in Table 2, the OA, BOR, and NBOR of result after changing scattering model are improved. Compared with traditional Yamaguchi–Wishart method, after using extended volume scattering model, the OA of EV–Wishart's result is increased by 2.8%. It can also be found in Fig. 5. There is more reasonable and accurate in boundary of buildings and non-
buildings, while traditional method shows more omission, especially in areas shown in Figs. 6 and 7. For areas shown in Figs. 6 and 7, when the directions of the structural trend of buildings are oriented with respect to radar illumination, the cross-polarisation components are increased in echo. In traditional Yamaguchi decomposition, for the most part, cross-polarisation components are assigned to volume scattering, lead to weak ability to identify this kind of buildings. After using

Fig. 3 Profiles of scattering components in red line 1 derived based on Yamaguchi decomposition (a) With traditional model, (b) With oriented angle compensation, (c) With extended volume scattering model

Fig. 4 Profiles of scattering components in red line 2 derived based on Yamaguchi decomposition (a) With traditional model, (b) With oriented angle compensation, (c) With extended volume scattering model

Fig. 5 Images of the study area (a) The ground truth map after registration containing reference samples for verification, blue and yellow represent buildings and non-buildings, (b) Results of building extraction using the method of Yamaguchi–Wishart, (c) Results of building extraction using the method of EV–Wishart, white and black represent buildings and non-buildings

Table 1 Ground truth reference samples

| No. of pixels | Buildings | Non-buildings |
|---------------|-----------|---------------|
| reference samples | 19,098    | 160,713       |

Fig. 6 Result details in region A (a) The ground truth maps after registration in region A of Fig. 5 and corresponding results of building extraction using the method of, (b) Yamaguchi–Wishart and (c) EV–Wishart. In results of building extraction, the white represents the building areas, and the black areas are the non-buildings

Fig. 7 Result details in region B (a) The ground truth map after registration in region B of Fig. 5 and corresponding results of building extraction using the method of, (b) Yamaguchi–Wishart and (c) EV–Wishart. In results of building extraction, the white represents the building areas, and the black areas are the non-buildings
extended volume scattering model that accounts for the HV component caused by double-bounce structures versus vegetation scatter, the situation of volume scattering overestimated is improved.

The double-bounce scattering power tends to show dominance, which is conducive to distinguish between oriented buildings and vegetation for Wishart classifier.

Here, the omission of EV-Wishart method is analysed. For urban areas, the ground layout is complex. Some densely arranged adjacent flat-roof buildings tend to be misidentified as flat ground. Some sparse arranged small buildings mixed with non-buildings tend to be very weak, and their characteristics are not obvious, so that these buildings is difficult to identify. In conclusion, the proposed EV–Wishart method shows more dominant in identifying oriented buildings compared with Yamaguchi–Wishart method and achieves the aim of improving the extraction accuracy.

4 Conclusion

In this paper, an extended volume scattering model assisted scheme for building extraction is introduced. The focus of this paper is to detect buildings whose main surfaces are oriented with respect to radar beam. The proposed method allows Wishart classify to distinguish between oriented buildings and vegetation, since an extended volume scattering model is introduced into polarimetric decomposition. The developed building extraction method is employed to process fully polarimetric SAR images obtained by GF-3. The study results confirm the efficiency and accuracy of proposed method.

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6 References

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Table 2  Comparison of the results of Yamaguchi–Wishart and EV–Wishart

| Method          | OA (%) | BOR (%) | NBOR (%) |
|-----------------|--------|---------|----------|
| Yamaguchi–Wishart | 91.9%  | 26.7%   | 5.8%     |
| EV–Wishart      | 94.6%  | 19.5%   | 3.7%     |

Note: OA, BOR and NBOR represent overall accuracy, the building omission rate and the non-building omission rate, respectively.