Detection and Reconstruction of the Building Objects from Multi-Aspect SAR Images

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Abstract
Simple building objects are modeled as cuboids, and an approach for automatic reconstruction of 3D building objects from multi-aspect metric-resolution SAR images is developed. The edge detector of constant false alarm rate (CFAR) and a Hough transform technique for parallel line segment pairs are first employed to extract the parallelogram-like image of the building walls in SAR images. A set of probability density functions is presented describing the façade-images and their multi-aspect coherence. Then the maximum-likelihood estimation of object is derived from its multi-aspect object-images. An automatic reconstruction algorithm is further devised to match object-images of different aspects and finally reconstruct the building objects.

4-aspect simulated images of 4-aspect Pi-SAR images over the campus of Tohoku University, Japan are investigated. Reconstruction of building objects from their multi-aspect images shows the fidelity of the whole process chain and the feasibility of 3D objects automatic reconstruction from multi-aspect SAR images.

Keywords**:** Multi-aspect SAR images, Hough transform, building reconstruction

1. INTRODUCTION

With rapid advancement of SAR technology, metric-resolution SAR image-data have become more accessible. A SAR image is produced by complicated interactions of electromagnetic waves with the objects and the background scene. Due to the complexity and heterogeneity of distributed objects and structures, most previous works on normal resolution SAR imagery is restricted to conventional image processing, or interpretation of double-scattering mechanism for built-up areas. An electromagnetic scattering model for a simple building was studied based on geometrical optics and physical optics [1,2].

Reconstruction of 3D-objects from SAR images has become a key issue for information retrieval for SAR monitoring. 3D reconstruction of man-made object is usually based on interferometeric technique or fusion with other data resources, e.g. optical and GIS data. Recently, some studies on reconstruction of building objects from multi-incidence or multi-aspect high-resolution SAR images have been reported [3,4]. However, fully exploiting high-resolution (metric or sub-metric) polarimetric SAR data is still on the preliminary stage.

It has been noted that scattering from man-made objects produces bright spots in sub-metric resolution, but present strips/blocks image in metric resolution. This difference is largely attributed to the different imaging ways employed for different resolutions, for example, spotlight for sub-metric resolution, stripmap for metric resolution.

In this paper, we present an automatic method for detection and reconstruction of 3D objects from multi-aspect metric-resolution SAR images. The steps are as follows:

The linear profile of the building objects is regarded as the most prominent characteristics. The POL-CFAR detector, Hough transform, and corresponding image processing techniques are applied to detection of parallelogram-like façade-images of building objects. Results of simulated SAR images as well as real 4-aspect Pi-SAR images are given subsequently after each step.

A probabilistic description of the detected façade-images is presented. Maximum-likelihood estimation (ML) of building objects from multi-aspect observed façade-images is given. Eventually, in association with a hybrid priority rule of inversion reliability, an automatic algorithm is designed to match multi-aspect façade-images and reconstruct the building objects. Moreover, taking advantage of the multi-aspect coherence of building-images, a new iterative co-registration method is presented.

Finally, reconstruction results are presented, and good performance is evaluated comparing with ground truth data. It is also concluded that the reconstruction accuracy closely depends on the number of available aspects. In the end, a practicable scheme of the 3D-object reconstruction from satellite-borne SAR image is proposed.

2. OBJECT-IMAGE DETECTION

As shown in Figure 1, the scattering image of a simple building is produced by direct scattering from the wall/façade, roof and edges, double scattering from wall-ground and shadows projected etc. In metric resolution, the scattering produces bright strips/blocks from respective parts of the object. A key step of reconstruction is to identify and extract these strips/blocks.

For the case of a smooth wall/façade, the only double scattering term to be considered must follow a specific propagation path, i.e. wall (reflect) to ground (diffuse). Simple building object is taken into account and is modeled as a cuboid, and the spatial distribution of the building objects is assumed not crowded, i.e. without serious shadowing and superposition. The cuboid object is described by seven geometric parameters: 3D position, 3D size and orientation. Besides, the flat roof is assumed with much less scattering compared with the edges and façades.

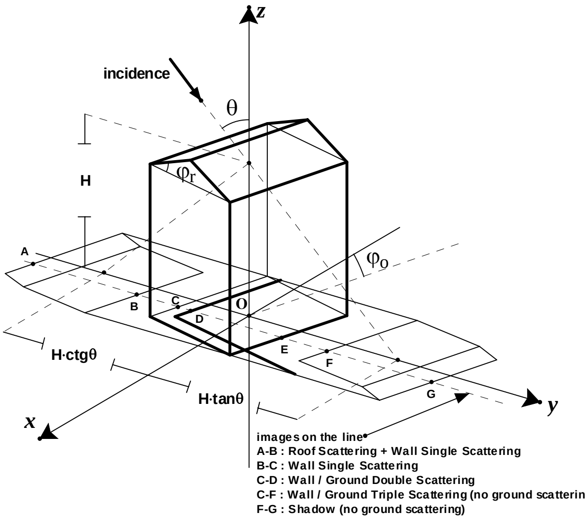


Figure 1. SAR imaging of a simple building model and its image composition

Fig. 2 shows (a) a model of the cuboid object, (b) its simulated SAR image, (b) using the mapping and projection algorithm [2], (c) a photo of real rectangular building, and (d) its image of Pi-SAR observation, respectively.

It can be seen from Figure 2 that the longer wall of the cuboid-like building, called as major wall henceforth, plays the dominant role in a SAR image. In this paper, main attention is focused on the major wall image. At the first step, the edge detectors of constant false alarm rate (CFAR) such as ratio gradient are used for edge detection.

To our experience, the POL-CFAR detector derived from complex Wishart distribution can fulfill the segmentation requirements of medium- and small-scale building-images. Besides, the ridge filter applied after this step can accommodate segmentation error to some extent.

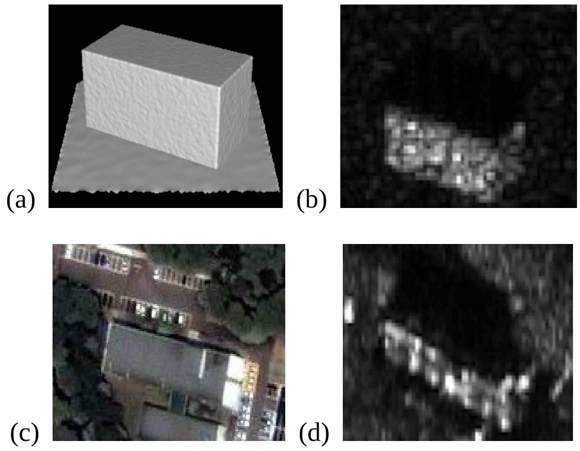


Figure 2. A cuboid object in m*-resolution SAR images*

In order to improve the segmentation precision, the detected edge by window-operator needs to be further thinned. Using the edge intensity produced in the POL-CFAR detection, an edge thinning method of ‘ridge filtering’ is presented. Taking an 8-neighbor 3×3 window as an example, the center pixel is regarded as on the ridge if its intensity is higher than the pixels along two sides.

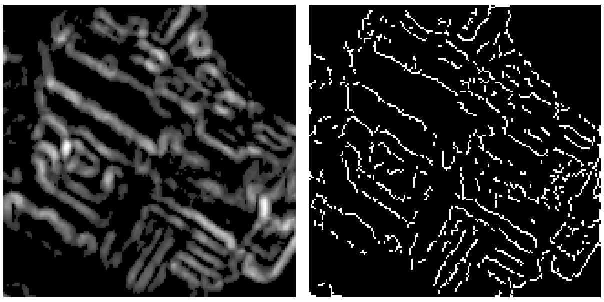
4-aspect Pi-SAR images acquired over Sendai, Japan by a square-loop flying path (Flight No. 8708, 8709, 8710, 8711, X-band, pixel resolution 1.25m) are taken as an example of real SAR image study. The region of interest (ROI) is the Aobayama campus of Tohoku University.

Fig.3 shows an aspect Pi-SAR images as an example.

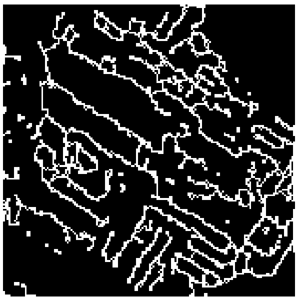
Figure 3. An aspect PI-SAR image

Fig.4 shows the results processed by the edge detection of Pi-SAR images.

The most distinct feature of a building object in SAR image is parallel lines. The Hough transform is employed to detect straight segments from the thinned edges, and parallelogram outlines of the façade-images can then be extracted. It is carried out in tiling manner in this paper, i.e. the original picture is partitioned into blocks, each of which is detected independently via Hough transform.



(a) edge detection (b) Level 4 ridge

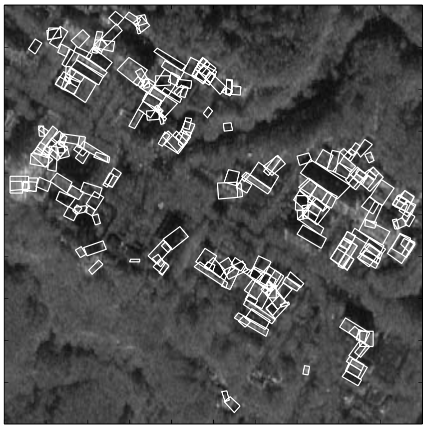


(c) Level 2 ridge

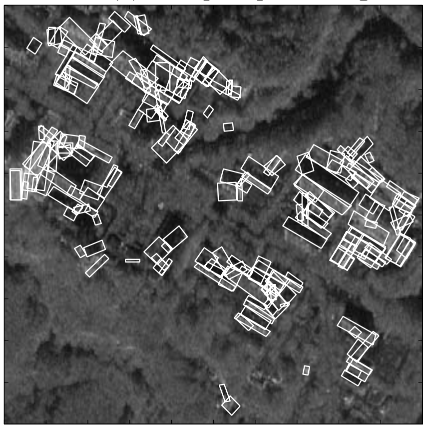
Figure 4. Edge detection

The detection steps of parallel line segments are: i) find bright spots in transform domain with a minimum distance between every two of them so as to avoid re-detection; ii) search the segments consisted of successive points along the corresponding parallel lines in spatial domain, which is longer than a minimum length, and the distance between two successive points is shorter than a maximum gap; iii) only the pairs of points lying on two lines and facing directly are taken into account for segment searching.

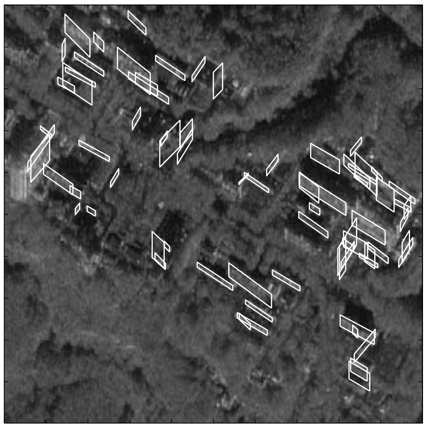
(a) first result via Hough transform



(b) after post-processing



(c) after end adjusting



(d) final building-images after offset-removed

Figure 5. Extraction of strip-like building-images

Figure 5(a-d) shows the detection from 4 aspects Pi-SAR images. Few building-images are not detected and some false images are wrongly produced. In fact, there is a compromise between over-detection and incomplete-detection. We prefer to preserve more detected building-images, so as to control the non-detected rate, while the false images are expected to be eliminated through the subsequent auto-selection of effective images for reconstruction. However, there always remain some undetectable images, attributable to shadowing of tree canopy, overlapping of nearby buildings or with too complicated wall structures.

The detected parallelogram of a homogenous scattering area could be direct scattering from façade, double scattering of wall-ground, combination of direct and double scatterings, projected shadow of building, or even strong scattering of strip-like objects (e.g. metal fence or metal awning), which is not considered in classification.

Shadowing is identified if scattering power of that area is much lower than the vicinity. Specifically, first set up two parallel equal-length strip windows on its two sides and then calculate the median scattering powers of the three regions. If the middle one is weaker than two sides, it is classified as shadow instead of building image.

The wall-ground double scattering can be differentiated from direct scattering based on polarimetric information. In this paper, the de-orientation parameter v [5] indicating the scattering mechanism is used to identify double scattering.

A left issue is to clarify the polarimetric calibration of multi-aspect Pi-SAR data. Main purpose is to compensate the imbalance between horizontally polarized and vertically polarized channels for building image classification. Detailed calibration is left to another paper.

3. BUILDING RECONSTRUCTION

Complexity of objects-terrain surfaces and image speckles incorporate certain uncertainty for detection of object images. To well describe multi-aspect object image, the parameterized probability is introduced for further proceeding of automatic reconstruction. For convenience, the detected building-images are parameterized. Generally, the edge pixels detected by CFAR are randomly situated around the real, or say, theoretical boundary of the object. It is reasonable to presume that the deviation distances of the edge points follow a normal distribution.

The original edge can be equivalently treated as a set of independent edge points. The line detection approach is considered as an equivalent linear regression, i.e. line fitting from random sample points. According to linear regression from independent normal samples, the slope of the fitted line follows the normal distribution.

All parameters have normal distributions and their variances are determined by the variance of the edge points deviation. After counting the deviation of the edge points in the vicinity of each lateral of all detected building-images and making its histogram, the variance can be determined through a minimum square error (MSE) fitting of the histogram using normal probability density function (PDF). The 4-aspect Pi-SAR images are counted.

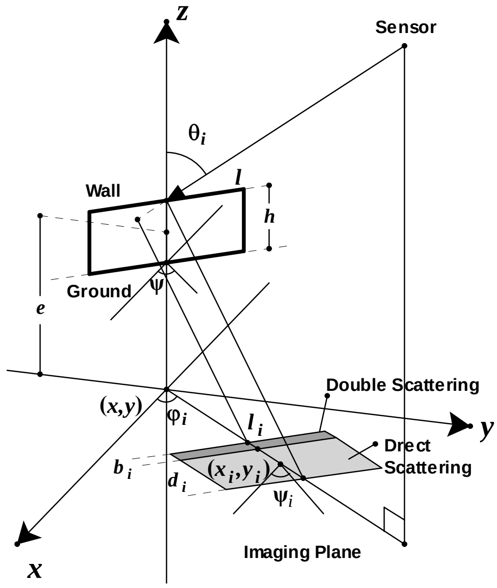


Figure 3. Geometry of a wall/façade imaging

Given a group of building-images detected from multi-aspect SAR images, the corresponding maximum-likelihood probability can be further used as an assessment of the coherence among this group of multi-aspect images. A large maximum-likelihood probability indicates a strong coherence among the group of multi-aspect building-images, and vice versa.

Multi-aspect co-registration, as a critical pre-processing step, is necessary when dealing with real SAR data.

Given the specification of a ROI, e.g. the longitudes and latitudes, the corresponding area in SAR image of each aspect can be coarsely delimited according to its orbit parameters. It can be regarded as a coarse co-registration step. Manual intervention is necessary if the orbit parameters are not accurate enough.

Only parameters of the building-images are needed to be co-registered to the global coordinates, but rather than the original SAR images. It is regarded as a fine co-registration step. In this paper, only linear co-registrations are considered. A simple and effective method should be manually choosing ground control points. In general, a featured terrain object or building is first selected as the reference of zero-elevation, and then its locations of different aspects are pinpointed. Coherence among multi-aspect building-images is the basis of automatic reconstruction.

Finally, an automatic multi-aspect reconstruction algorithm is designed. The building objects are reconstructed from the 4-aspect simulated SAR images. The inversion accuracy is very good. 错误！未找到引用源。 shows the 3D reconstructed objects on the true DEM. It seems the inverted elevations also match well with the true DEM.

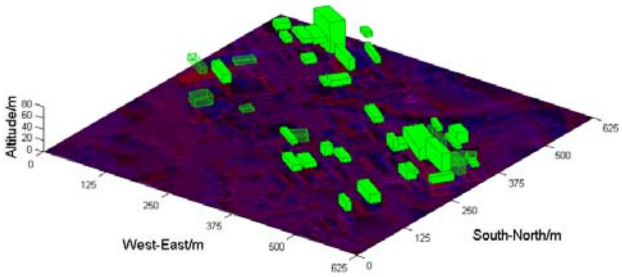


Figure 4. 3D reconstructed objects

Due to the difficulty for authors to collect ground truth data, a high-resolution satellite optical picture (0.6m QuickBird data) is used as a reference. Geometric parameters of each building manually measured from the picture are taken as ground truth data to evaluate the accuracy of reconstruction. The satellite picture is co-registered to SAR images and shown in Fig. 5, where the reconstructed SBTs and corresponding real buildings are labeled out.

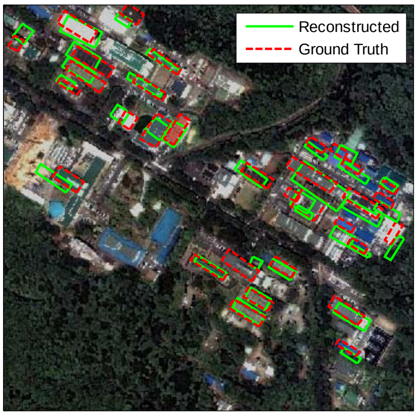


Figure 5. Comparison of reconstructed buildings with real buildings on optical picture (dashed lines are the roofs of real buildings).

4. DISCUSSIONS

There is a trade-off between the false and correct reconstruction rates. If we increase the false alarm rate of edge detector, relax the requirements of building-image detection and/or increase the false alarm rate of judging correctly matched group, it will raise the reconstruction rate, but also boost the false reconstruction rate. Efficiency will be deteriorated if the false reconstruction rate goes too high. On the contrary, the false reconstruction rate can be reduced and the accuracy of reconstructed buildings can be improved, but the reconstruction rate will also decline.

A critical factor confining the reconstruction precision should be the number of effective aspects, hereafter referred as effective aspect number (EAN).T he reconstruction result will become better if more SAR images of different aspects are available.

Main error of reconstruction is caused by the boundary-deviation of detected building-images, which is originated from complicated scattering and interactions of spatially distributed objects and backgrounds. In probabilistic description of detected building-image, the presented boundary in SAR image is seen as the same as reality. However, the real detected building-image might be biased or even partly lost due to the obstacle and overlapping.

In addition, it is noticed that large-scale buildings might not be well reconstructed. The reason is partly attributed to the premise of Wishart distribution of POL-CFAR detector. Since the images of large-scale buildings might reveal more detail information about the texture feature and heterogeneity, it deteriorates the performance of edge detector. To develop a new edge detector based on certain specific speckle model for high-resolution images can improve the results. Another more feasible way is to employ a multi-scale analysis, through which building-images of different scales can present Gaussian properties in their own scale levels. Of course, the expense for multi-scale analysis might be a loss in precision.

Another issue to be addressed is the exploitation of multi-aspect polarimetric scattering information. In heterogeneous urban area, the terrain objects appear distinctively in different aspects, which gives rise to a very low coherence between their multi-aspect scatterings. Hence, polarimetric scattering information may not be a good option for the fusion of multi-aspect SAR images over urban area

After the ROI is coarsely chosen in each aspect image, edge detection and object-image extraction are carried out, subsequently. Then the object-images are parameterized and finely co-registered. As long as multi-aspect object-images are automatically matched, 3D objects are reconstructed at the same time.

The merits of this approach are the process automation with few manual interventions, the fully utilization of all-aspect information, and the high efficiency for computer processing. Making a reconstruction on a 4-aspect Pi-SAR dataset (500×500) takes less than 10 min CPU time (CPU frequency 3GHz). Complexity of this approach is about $O(KN^2)$, where K is the aspect number and N is the size of SAR images (K=4, N=500 in this case).

It is tractable to extend this approach to reconstruction of other kinds of objects. For other types of primary objects, given the *a priori* knowledge, new image detection methods have to be developed. It is possible to treat more complicated buildings as combinations of different primary objects, which can be reconstructed separately and then combine together.

Considering a space-borne SAR with the functions of left/right side looking (e.g. Radarsat2 SAR) and forward/backward oblique side looking (e.g. PRISM in ALOS), six different aspect settings are available for ascending orbit. There is a 20° angle between ascending and descending flights for sun-synchronous orbit. Therefore, it can observe from 12 different aspects. Suppose the sensor use different aspect in each visit and the repeat period is 15 days, a set of SAR images acquired from 12 aspects can be obtained through a 3-month observation. Then, application of SBT reconstruction with acceptable precision.

More detailed discussions can be seen from [6].

5. OTHER RELATED PROGRESS

Other progress related with Pi-SAR and ALOS SAR can be briefly listed in Figs. 6 and 7.

Fig. 6 is reconstruction of the buildings and vehicles on the streets from two opposite directions flkights of Pi-SAR.

Fig. 7 is an VH image of Naruto Bridge, and the processed image of single, double and triple scattering for inversion of the bridge height. The inversion result of the bridge height is very good in comparison with ground truth data. More discussion will be presented in another papers.

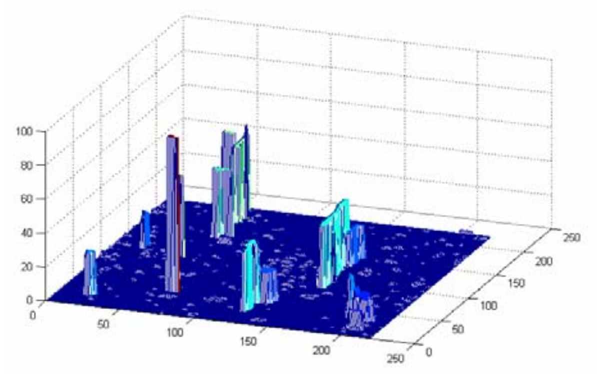


Figure 6. Reconstruction of the buildings and vehicles on the streets

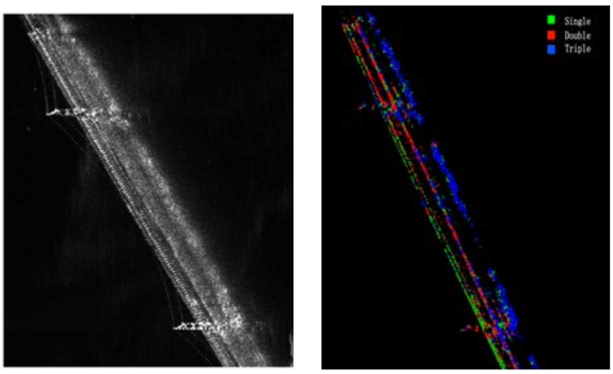


Figure 7. ALOS SAR VH-image, and clasification of single, double and triple scattering for inversion of bridge height

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