BUILDING DETECTION AND FOOTPRINT RECONSTRUCTION FROM SINGLE VHR SAR IMAGES

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1. INTRODUCTION

Spaceborne very high resolution (VHR) synthetic aperture radar (SAR) images with meter and sub-meter resolution permit to extract information from urban areas at the level of individual buildings. In order to exploit this information for various application scenarios (e.g. emergency response after natural disasters), robust building detection and reconstruction methods are essential. Different techniques for building detection and reconstruction from VHR SAR have been proposed in the literature [1, 2, 3]. They mainly rely on the availability of multi-modal data which implies multiple acquisitions with different viewing configurations (changed incidence- and/or aspect angle). However, with the available technology those data cannot be acquired with a single pass, but only after different passes. Thus, the timely availability of such data is not guaranteed. This is of major concern for damage assessment purposes, which exploiting the key advantages of SAR data (independence on the weather conditions and the solar illumination) is a prime application scenario for VHR SAR imagery. In [4], we presented a method for building detection from single detected VHR SAR images, which is suitable for the data acquired from currently operational spaceborne VHR SAR missions. It is based on the extraction of a set of primitives and on their composition to building candidates based on the semantic meaning of the extracted primitives. The semantic meaning is evaluated as the degree of membership of a primitive to a certain scattering class (e.g. facade, flat roof), which allows one a quantitative evaluation of the reliability of the derived building candidates. This additional information partially compensate for the low number of building features detectable in single VHR SAR images.

In this paper, we improve and extend the building detection method presented in [4] for the estimation of the 2D footprints of the buildings. In particular, under the assumption that the buildings have approximately a parallelepiped shape, we reconstruct their footprints by analyzing the features which compose the building hypotheses. In order to handle the computational complexity of the proposed method we designed the algorithm for a computer cluster, which allows the processing of an entire VHR SAR scene. We present and discuss experimental results obtained on a spaceborne VHR SAR image (about 1 m resolution) of a residential area.

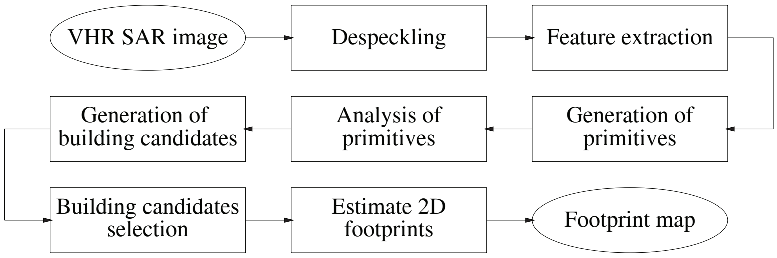

Fig. 1. Processing chain of the footprint detection and reconstruction algorithm.

2. PROPOSED METHODOLOGY

2.1. Detection and reconstruction of building footprints

Let us consider a simple flat roof building model. Due to the ranging geometry of radar sensors, its footprint is formed by different scattering mechanisms: layover, double bounce, single scattering from the roof, and shadow [5]. The outlined ordering of the various contributions of the building to the overall backscatter depends on the geometry of the structure (i.e. shape, height, and width) and the viewing configuration of the sensor (in terms of incidence and aspect angle of the building). On the one hand, when dealing with spaceborne VHR SAR images, the incidence angle over an urban area is almost constant and calculable for each acquisition. On the other hand, the buildings present variable aspect angles that are not known a priori.

In order to detect and reconstruct buildings from a single VHR SAR acquisition, we propose the algorithm described by the block scheme presented in Fig. 1, which is made up of seven steps: i) speckle filtering; ii) feature extraction; iii) generation of primitives; iv) analysis of primitives; v) generation of building candidates; vi) selection of candidates; and vii) 2D footprints reconstruction. Before feature extraction, the input image is filtered for reducing the speckle by using the Gamma MAP filter. The features that we extract are: the bright lines, the bright areas, and the shadows. The extracted features are vectorized and characterized by a set of attributes. From this point onward the algorithm operates in the vector domain. In the next step, the algorithm searches for features of the same type which are close and with similar orientation in order to compose them to bigger objects, when possible. This is performed by means of a production system, which is a concept introduced in artificial intelligence that has already been used in state-of-the-art building detection algorithms [1, 3, 6]. A set of attributes is calculated also for the new objects. The set of simple and composed features are considered as primitives for the following steps. We estimate the semantic meaning of each line or bright area primitive by calculating its membership to a set of semantic classes. We defined six semantic classes for both bright lines and areas: *facade*, *double bounce*, *line from roof*, *strong scattering from roof*, *flat roof*, and *gable roof*. The membership degree of each primitive to these classes is computed on the basis of the attributes that have been stored for each object in the previous steps, according to a set of *membership functions* (MF) derived empirically for each class. It is worth noting that each membership degree is calculated independently from the others. As a result, each primitive can have high membership values to different classes at the same time. Starting from the set of primitives, a set of building candidates is generated by composing the input primitives according to a set of rules that take into account the viewing configuration of the sensor. Indeed, for one actual building many building candidates are generated. As some false alarms may arise, we select the most probable building candidates on the basis of a score, which is computed for each candidate using the membership degrees

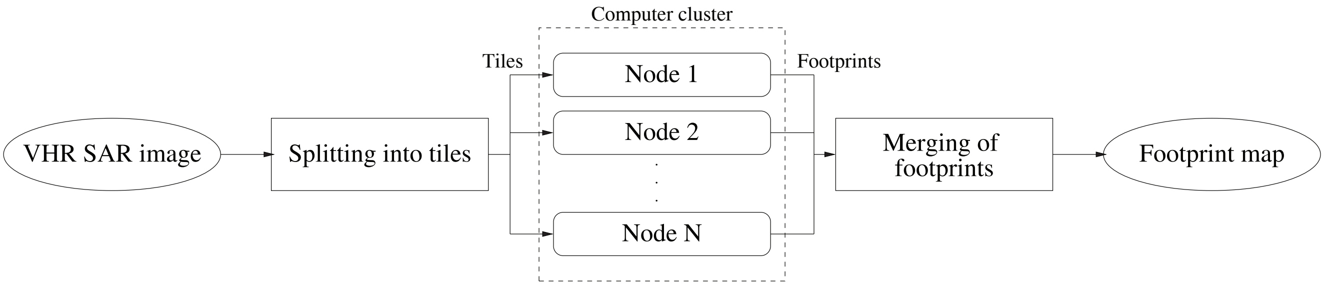

Fig. 2. Proposed computing architecture to perform the building detection and reconstruction method on entire VHR SAR scene.

and the relative positions of the primitives composing the hypothesis. The candidates with a score higher than a user defined threshold are selected as input to the last step. The final step aims at refining the results obtained in the previous steps and at reconstructing the 2D footprint assuming that the corresponding building has approximately a parallelepiped shape. This is achieved by analyzing the areas corresponding to the building candidates and the primitives which they contain. It is worth noting that candidates composed by different sets of primitives may overlap over the same real footprint, which is taken into account for the footprint reconstruction.

2.2. Analysis of extended scenes

The processing chain described in the previous section is computationally expensive. In particular, the generation of building candidates is complex and depends on the number of primitives that have been inserted in the production net. Considering an entire scene, the number of primitives is significant and the generation of building candidates, which is of non linear complexity with respect to the number of inserted primitives, cannot be performed on latest high performance workstations. This reduces the size of the processable input image to a small subset of an actual VHR SAR scene, so that the method cannot be used in the context of a real application scenario. In order to face this problem, we developed the algorithm on a computer cluster infrastructure [7]. In such a framework, the nodes in the cluster process different subsets of the input image in parallel. Each subset contains only few primitives so that the building candidates can be generated in a fast manner on state-of-the-art hardware. In Fig. 2 a block scheme of the architecture is presented. As a first step, the VHR SAR image is split into tiles. Every tile overlaps with its neighboring tiles to assure that buildings located at the tile borders are detected and reconstructed properly. Then, the tiles are distributed across the nodes which independently execute the proposed detection and reconstruction algorithm. Finally, the results for each tile are merged in order to generate the final footprint map for the entire input scene.

Table 1. Algorithm performance in terms of number of detected buildings, missed alarms and false alarms.

Building type	**Number of buildings**	**Detected buildings**	**Missed alarms**	**False alarms**
Flat roof	11	11	0	-
Gable roof	8	6	2	-
Total	19	17	2	2

3. EXPERIMENTAL RESULTS AND CONCLUSIONS

We tested the building detection algorithm (without 2D footprint reconstruction) on a TerraSAR-X meter resolution spaceborne SAR image of the city of Dorsten, Germany. The detection results for a set of flat- and gable roof residential buildings at different aspect angles showed that the method has in overall a good detection rate, with only few false alarms (see Tab. 1). The analysis pointed out that missed alarms refer to buildings for which no features have been extracted, e.g. buildings occluded from the radar beam by other taller objects, such as trees or buildings, located at the sensor close side. Indeed, those buildings are even difficult to detect by experienced SAR image interpreters. The classification of the detected buildings according to their type gives some additional information. However, some footprints corresponding to single buildings have been split in two or more parts. Moreover, even though a building has been correctly detected, the footprint based only on the objects extracted in the feature extraction step is often not complete or presents a non-realistic shape. Nonetheless, the extension of the processing chain with the reconstruction step demonstrated to solve most of these problems. Finally, the porting of the algorithm to a computer cluster allowed us to process an entire VHR SAR scene. This supports the testing of the method for a large set of buildings, which is essential to evaluate the characteristics and the robustness of the presented algorithm. Greater details on the proposed 2D footprint reconstruction technique, the computing framework and the corresponding results will be reported in the full paper.

4. REFERENCES

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