New opportunities and challenges for analysis of urban areas in high resolution SAR data

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Abstract

Leading-edge airborne SAR sensors provide spatial resolutions in the order of decimeters. In such data many features of urban objects can be identified, which were beyond the scope of radar remote sensing before. In this paper, the impact of high-resolution SAR data on the analysis of urban scenes is discussed. An example for the new quality of the appearance of buildings in such data is given and interpreted. The fine level of detail opens the opportunity to reconstruct the structure of man-made objects (e.g. buildings). The problem of the high computational load required for the processing and the image analysis of high-resolution SAR data is discussed. Finally, the topics geocoding and data fusion are addressed.

1 Introduction

The image analysis concept for SAR data has to match the features of the studied imagery, e.g. the spatial resolution. In case of satellite data (like ERS 1 with about 25m resolution), the analysis is often restricted to radiometric image properties, even in urban areas. Usually a partitioning of the scene in different terrain classes (e.g. forest, grass, rocks, suburban, urban) is carried out, based on empirical statistical models [17] of the backscatter characteristic of materials.

In the 90's, airborne SAR sensors achieved spatial resolutions of about one meter in range and even better in azimuth. For example, the AER-II system [5] was capable of single-pass along- and across-track interferometry as well as of multi-polarization data acquisition. In urban scenes, the analysis of the polarization matrix is useful for the discrimination of man-made-objects from volume scattering (e.g. trees). Furthermore, techniques have been developed to distinguish superimposed scattering mechanisms in polarimetric InSAR data [8]. Due to the better resolution, geometric features of urban objects can be identified in such SAR images. Therefore, the focus of the image interpretation shifted from radiometric to geometric properties of man-made objects like buildings. Characteristics of those are piecewise plane surfaces, sharp edges, and a mainly linear, right-angled, or parallel structure. This peculiarity gives rise to frequently observed dominant scattering at building locations, e.g. caused by specular reflection at tilted roofs facing towards the sensor, double-bounce between the building facade and the ground in front and triple-bounce reflection at trihedral corner structures [4]. A further important building feature is the cast shadow on the ground behind. In general, the mapping of a certain urban area is heavily dependent on aspect and elevation angle [7]. The mentioned characteristics have been exploited for model-based structural image analysis approaches, e.g. for building reconstruction [14], damage detection [11] or the grouping of regular point structures [16].

Today, leading-edge airborne SAR systems can resolve objects of size even below a decimeter [6]. The focus of this paper is to discuss the new opportunities and challenges for the analysis of urban areas, which arise from the availability of high-resolution SAR data. Of course, one main benefit is that additional object structures become now visible in the data. In Chapter 2, the appearance of buildings will be discussed. The consequences of the high level of detail for the image analysis are investigated in Chapter 3. Examples for object segmentations in such imagery are given. Furthermore, the outlines of a concept are presented in order to limit the computational load, based on multi-scale SAR processing [1] and the screening for regions of interest [10]. In Chapter 4, the topic data fusion with complementary information is addressed with respect to the geocoding of the SAR imagery [12] and the support of the image interpretation [13].

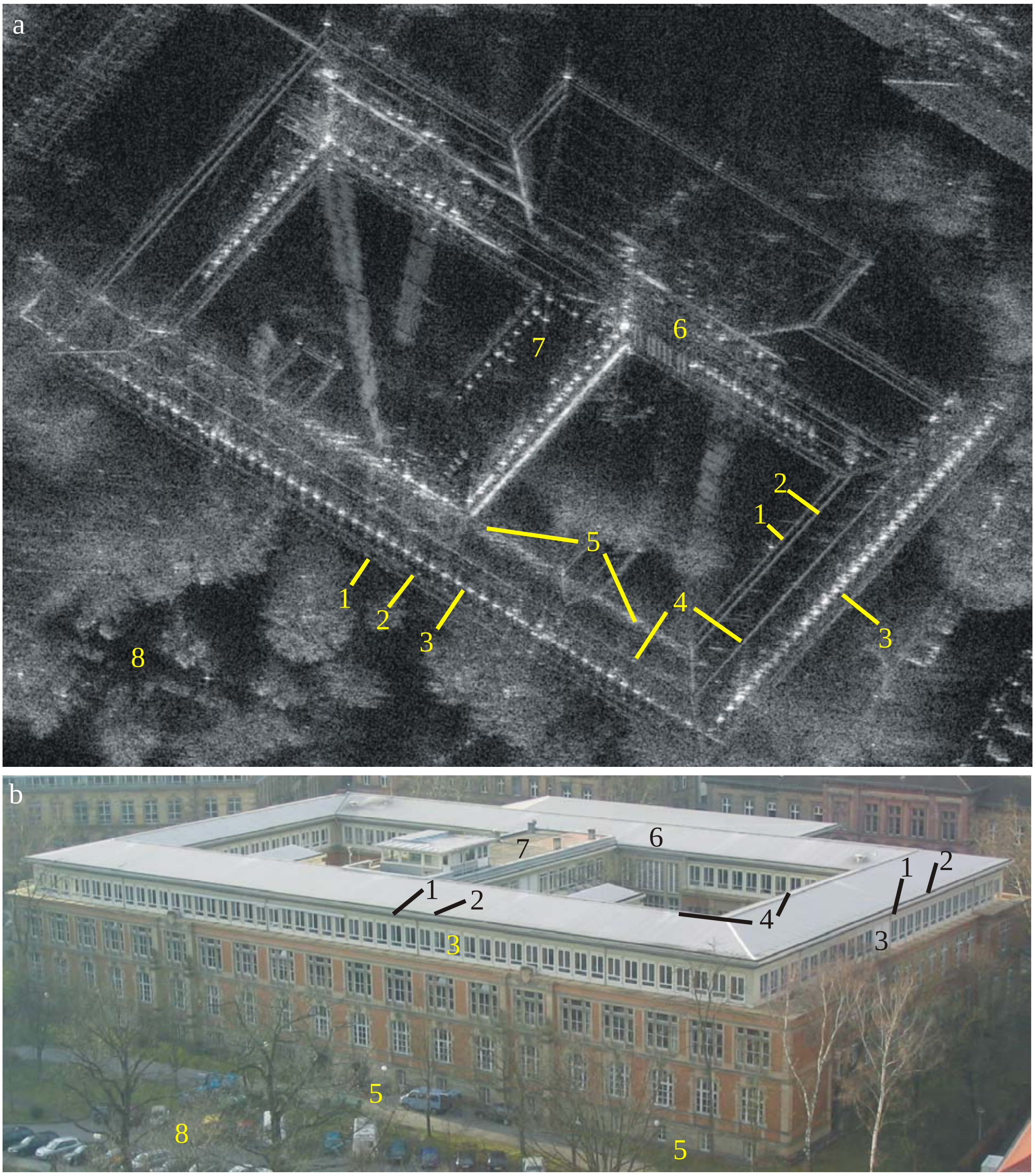

Fig 1. a) SAR image (range direction is bottom-up), b) photograph (numbers 1-8 see text)

2 Appearance of buildings in high-resolution SAR data

The appearance of buildings in high-resolution SAR images is discussed using a building of the test area Karlsruhe University campus (Germany). In Fig. 1a a SAR image (August 2002) and in Fig. 1b a photograph (February 2004) of the same building are shown. The SAR data were acquired by the PAMIR sensor [2] of FGAN. The resolution of this multilook image is slightly better than 20cm in range and azimuth (X-band, HH polarization, off-nadir angle 60°, range direction is bottom-up). The subset of the SAR data chosen here covers an area of 100m x 80m. The shown image - and other already processed data - indicates, that particularly buildings look very different compared to lower resolution imagery. One reason for this is the large dynamic range of the data, in this case about 70 dB. In the following, the potential of high-resolution SAR data for urban analysis is demonstrated with some examples. The eaves (*1*, *2)* and the ridge (*4)* of the roof can clearly be identified as linear structures, even inside the layover region in the lower image part and at the rear building area. The roof planes appear dark, because they are made of metal plates and the signal is mainly reflected away from the sensor. Very interesting are the linear structures of equidistant point scatterers (*3)* located at the front walls close to the sensor. The most probable source of these effects are slighly elevated metal stripes connecting the metal plates on the small roof between the middle and the top floor. Despite the presence of some deciduous trees in front of the building, which were full of leaves at the time of the SAR data recording, the double-bounce scattering between the walls and the ground in front can be seen (*5*). At the backward facade of the right courtyard, the special structure of the row of windows (*6)* is preserved in the SAR image. On the terrace (*7)* in the middle of the building complex some small pillars and a railing (hardly visible in the photograph) are located. Those objects are mapped to point structures in the SAR image. Surprisingly, the superstructure on the terrace can not be matched with a correspondence in the SAR image. The reason for this is not understood yet. At the parking lot (*8)* some cars are visible, even though their signal is partly obscured by layover from trees.

3 Consequences for the image analysis

3.1 Object segmentation

The availability of high-resolution SAR data offers the opportunity to determine the geometry of man-made objects. Frequently observed features of this kind are straight edges, right angles, and regular or parallel alignment of object groups. First segmentation results are shown in Fig. 2a-c: edge detection [3] (Fig. 2a), line detection [15] (Fig. 2b), and a grouping (yellow, Fig. 2c) [16] of linearly arranged and equidistantly spaced point scatterers (red). The main building features could be detected in the test image. Starting from these sets of primitive objects, the structure of the building (the footprint and – to some extent – the roof) could be reconstructed. Beside the object geometry, further constraints can be modeled for this purpose, e.g. the layover area has to be located closer to the sensor than the cast shadow from the building [14]. The building height can be obtained either from InSAR data, the length of the shadow area, or the length of the layover region.
Especially in case of man-made objects, only a few or even a single scattering structure might be present in the small resolution cell. Hence, polarimetry is expected to become a key technique for object classification [8] and the determination of object orientations.

3.2 Multi-scale processing and screening

The better the desired geometric resolution of a given area gets, the higher the computational load becomes for the SAR image formation and the subsequent image analysis. However, often only a subset of the scene is in the focus of interest. In order to save time, a multi-scale [1] strategy is appropriate. First, an overview image is processed with a fast sub-optimal

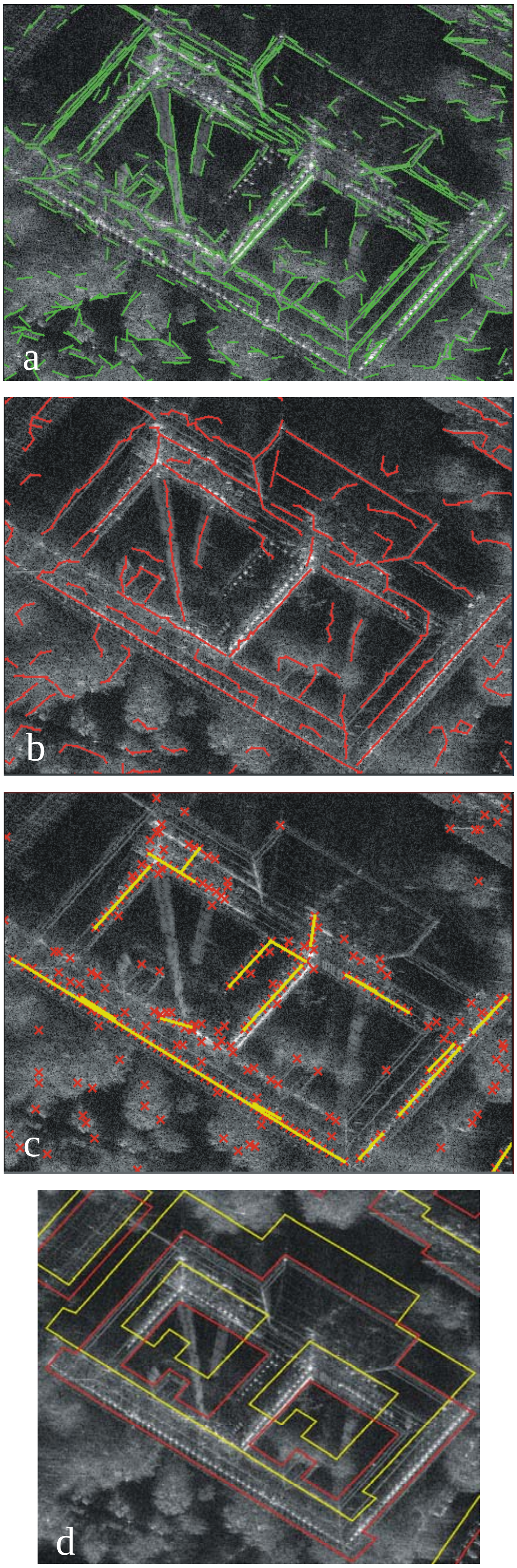

Fig 2. a) Burns edge segmentation, b) Steger line segmentation, c) dominant point scatterers (red) and grouped linear scatterers (yellow), d) SAR image superimposed with building footprints (yellow) and predicted roof position (red).

processor. In a subsequent screening process, regions of interest are identified [10] in the overview image. Afterwards, these regions are re-processed in full resolution. Finally, a focused image analysis is carried out in the full resolution subset of the data.

4 Geocoding and Data Fusion

Another important topic is the geocoding of high resolution SAR data, e.g. for data fusion. If no InSAR data is acquired, an external digital elevation model (DEM) is required for this purpose. In order to map elevated objects like buildings on the correct position, the geocoding should be based on a DEM of comparable resolution and high accuracy. In case of a first-pulse LIDAR DEM, the influence of trees on the visibility of objects can be modeled [12].

The analysis of SAR images is a demanding task even for experts. The interpretation can be supported by a fusion of SAR data with complementing information from other sources for comparison. This is illustrated in Fig. 2d: the slant range SAR image is superimposed with building footprints from a map (yellow), according to the given flight path and sensor parameters. Due to the sensor principle, the elevated building appears shifted towards the sensor. In order to predict this shift, the mean height of the buildings was calculated from a LIDAR DEM. Then the building outlines (red) were projected again onto the image [13]. They match now better the building in the SAR image.

5 Conclusion

State-of-the-art high-resolution SAR sensors provide a detailed mapping of man-made objects, which could not be achieved by radar remote sensing only a few yours ago. Structural image analysis approaches were up to now either tailored for extended targets or the extraction of rather coarse scene descriptions. Based on the new high-resolution data, a much finer level of detail of the object recognition seems to be possible. Polarimetry is expected to be of growing relevance for the analysis of urban areas. The geocoding accuracy should match the resolution of the SAR data. This is a prerequisite e.g. for the fusion of multi-aspect SAR data or the fusion of SAR data with complementing data of different kind.

6 Literature

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