Building Recognition from Multi-Aspect High-Resolution Interferometric SAR Data in Urban Areas

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ABSTRACT

The improved ground resolution of state-of-the-art synthetic aperture radar (SAR) sensors suggests utilizing this technique for analysis of urban areas. However, building reconstruction from SAR or InSAR data suffers from consequences of the inherent oblique scene illumination, such as foreshortening, layover, occlusion by radar shadow and multipath signal propagation. Especially in built-up areas, building reconstruction is often hardly possible based on single SAR or InSAR data sets alone. An approach is presented to improve the reconstruction quality combining multi-aspect InSAR data.

Building object primitives are extracted independently for two directions from the magnitude and phase information of the interferometric data. After projection of these initial primitive objects from slant range into the world coordinate system they are fused. This set of primitive objects is used to generate building hypotheses. SAR illumination effects are discussed using real and simulated data. The simulation results have been compared with real imagery. Deviations between simulations and real data were the base for further investigations. The approach is demonstrated for two InSAR data sets of a building group in an urban environment, which have been taken from orthogonal viewing directions with spatial resolution of about 30 cm.

Keywords: multi-aspect, high-resolution, interferometric SAR, building reconstruction

1. INTRODUCTION

The physical principle of SAR sensors is responsible for specific phenomena [1] such as foreshortening, layover, shadow and multipath propagation. These phenomena, which occur preferred at building locations, especially in dense built-up areas, hamper the analysis of SAR images. 3D-building recognition from SAR and InSAR data has been studied for city cores with high buildings [2], rural areas [3] and industrial plants [4]. Especially in dense urban environment building recognition is difficult because of the effects mentioned before. If context knowledge derived from the typical appearance of buildings in SAR data is utilized by a model-based reconstruction approach, then building recognition can be simplified. The detection results are improved by using high-resolution data providing more building features and a combination of multi-aspect SAR data to compensate partly the interfering illumination effects.

This paper is organized as follows. In section 2 the test data set is introduced. The special illumination effects of SAR from different aspects in vicinity of buildings are discussed in section 3. The model-based approach for the detection and reconstruction of buildings from multi-aspect InSAR data is described in section 4 and the results in comparison to LIDAR data are shown in section 5.

2. MULTI-ASPECT INSAR DATA

The appearance of buildings in multi-aspect high-resolution SAR images is discussed using a data set covering a part of the city Dorsten (Germany). The recording of the InSAR data was taken from a single pass interferometric antenna configuration. Both antennas alternatively illuminate the scene and receive the backscattered complex signals (ping-pong mode). The InSAR-SLC data (Intermap [5]) have a spatial resolution in slant geometry of about 38 cm in range and 16 cm in azimuth direction. The sensor operated in X-band with a wavelength $\lambda \approx 3$cm, an effective baseline $B \approx 2.4$ m and varying off-nadir angle θ from 28° (near range) to 52° (far range). The set of images was taken in approximately 3000 m height above ground two times from two flight directions spanning an angle of about 90°, so that

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from each direction two image pairs were recorded. The flight course is north south and west east aligned, which results in very different illumination effects at buildings with same orientation.

Figure 1 Multi-aspect InSAR magnitude images

The overlapping area (see Figure 1) covers five square kilometres of an urban area with partly high density of buildings of different types. Interesting are the mixture of industrial and residential areas, which are characterised by regular groups of buildings often aligned in north-south direction and parallel to roads. Furthermore, dense built-up areas and high vegetation density are typical for the scenery.

3. APPEARANCE OF BUILDINGS IN MULTI-ASPECT SAR IMAGES

In a first step of the study typical SAR illumination effects were investigated and simulated [6], [7] in principle. Figure 2 illustrates schematically typical effects at flat roofed buildings in the case of orthogonal viewing directions. In first and second row (I,II) the signalling pathway at building locations is depicted. The grey values at third row (III) correspond to expected magnitude values at same locations. For comparison in Figure 3 the different illumination effects are depicted in simulated (a,c) and real (b,d) magnitude images for both flight directions at three significant sub areas. The layover phenomenon occurs at locations with steep elevation gradient facing toward the sensor, such as at vertical building walls. Layover areas appear bright in the SAR image (see Figure 2). Perpendicular alignment of buildings to the sensor leads to strong signal responses by double-bounce scattering at the dihedral corner reflector between ground and building wall. This results in a line of bright scattering. Depending on façade structure and roughness this effect sometimes is observed as well for tilted buildings. At the opposite building side the ground is partly occluded by building shadow, which appears as a dark region. Roof structures may either lead to strong response, to homogeneous amplitude regions or to dark regions with e.g. line structures as can be seen in Figure 3b,d. Due to urban diversity in built-up areas usually all these kinds of backscattering are observable dependent on roof types (e.g. flat or gabled), on orientation of buildings towards the sensor and on roof material properties. Keeping this in mind, mapping of an object under different illuminations, pose to be a challenge for the analysis.

The urban structure in the magnitude images of the present data appears different compared to data sets used in former investigations [4]. This difference is partially originated by the high density of buildings and above all by the high spatial resolution. Especially in the built-up areas groups of small, long and higher houses are located. Buildings which are orientated with the long side towards the sensor appear only as long lines of bright scattering. No closed roof areas are visible. This effect is schematically illustrated in Figure 2a and observable in the second magnitude image tile of Figure 3b (yellow quadrangle). Figure 2b shows the situation for an orthogonal illumination of the same building. This results in short lines of bright scattering and visible closed roof areas in magnitude images (see Figure 3d – yellow quadrangle).

Frequently observed features are pairs of parallel lines as shown in last tile of Figure 3b,d (red quadrangle). These bright scatters are caused by gabled roofs orientated perpendicular towards the sensor. This can be ascribed to the high resolution of the data, which makes it possible to observe this feature even for small houses. Interaction effects caused by adjacent buildings and trees as can be seen in the first magnitude tiles of Figure 3b,d (green circle), have huge impact on the proposed building reconstruction approach described in the next section. However, the occurrence of these effects is affected by flight direction as shown in Figure 2 and Figure 3 and by the local off-nadir angle.

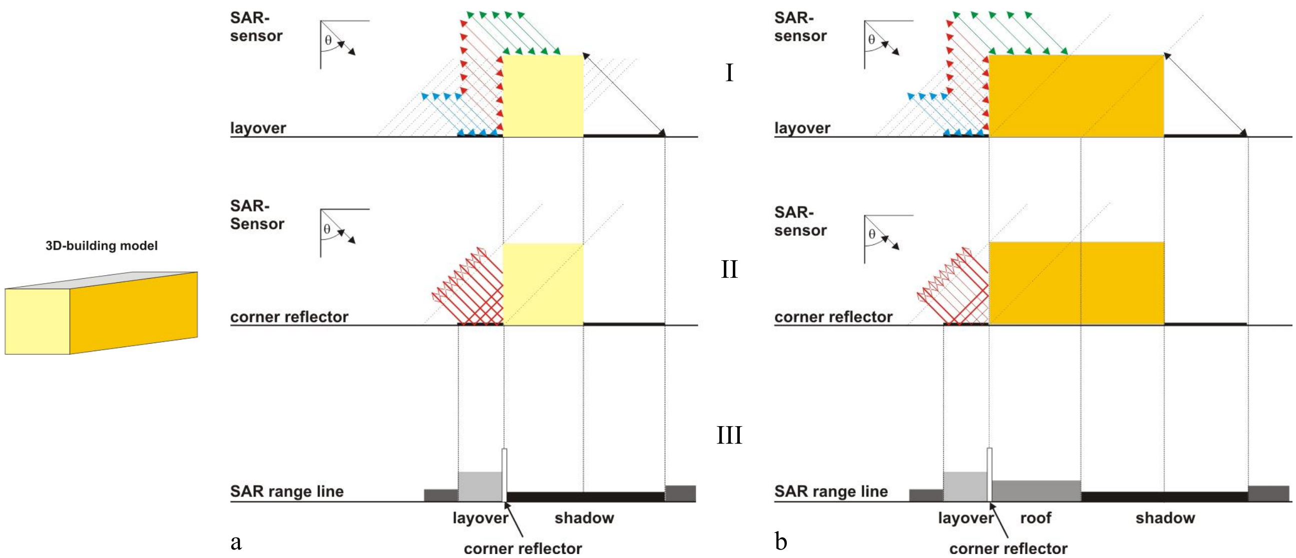


Figure 2 schematically illustrated SAR Phenomena at a cubical small and long building. Illumination orientated to long (a) and to short (b) building side.

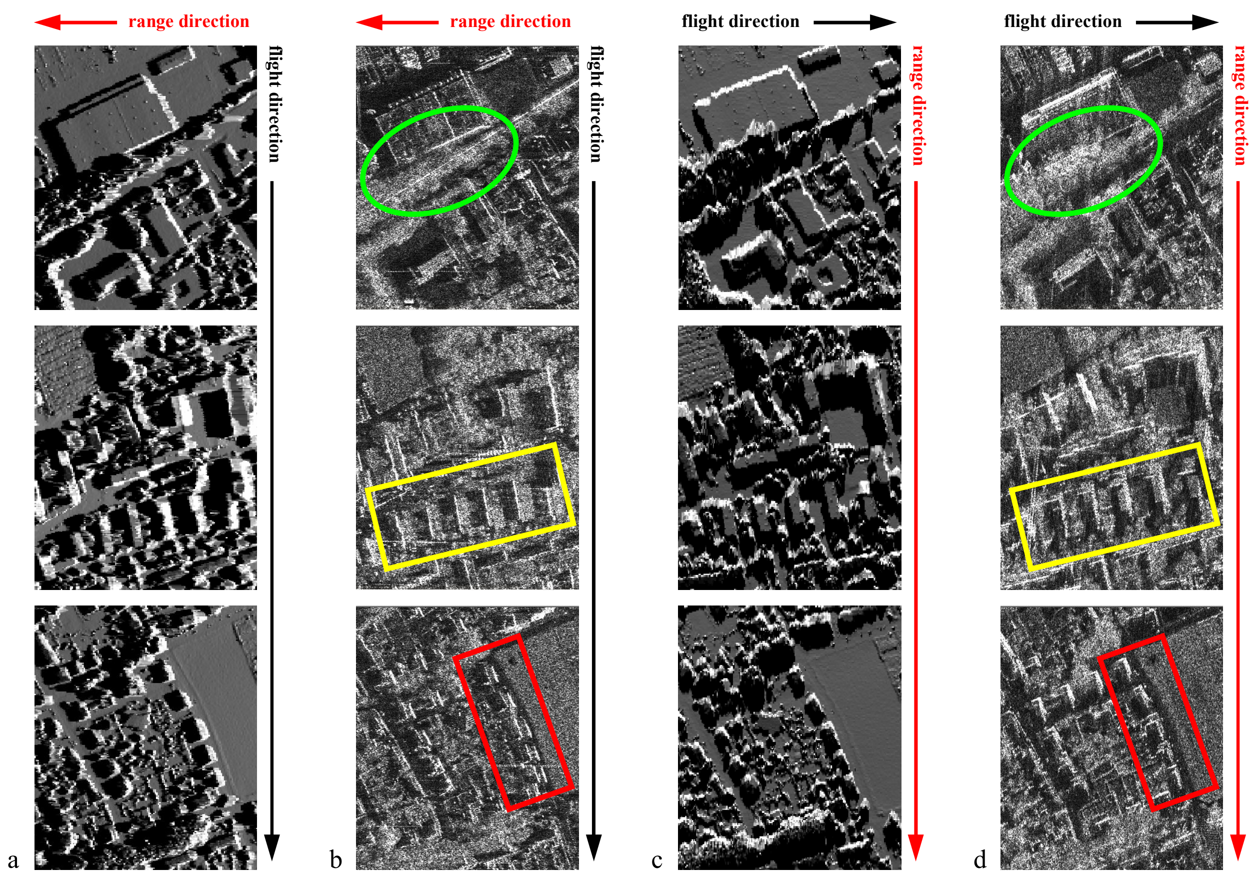


Figure 3 simulation of SAR Phenomena in flight direction north to south (a), west to east (c). Related magnitude image parts (b) and (d). In tiles of (b) and (d) illumination effects caused by trees (green circle) and in the vicinity of small and long buildings (yellow quadrangle) and gabled roof houses (red quadrangle) are shown.

4. APPROACH FOR BUILDING DETECTION AND RECONSTRUCTION

Some of the approaches proposed in the literature are based on the assumptions, that man-made objects have often right-angled structures. Additionally these objects are presenting the typical SAR effects in the magnitude image. But the appearance of two man-made objects can be completely different as shown in Figure 4. The left image was recorded by the AER-II sensor (FGAN-FHR, X-band, about 1 m spatial resolution) and the right one by the AeS (Intermap [5]).

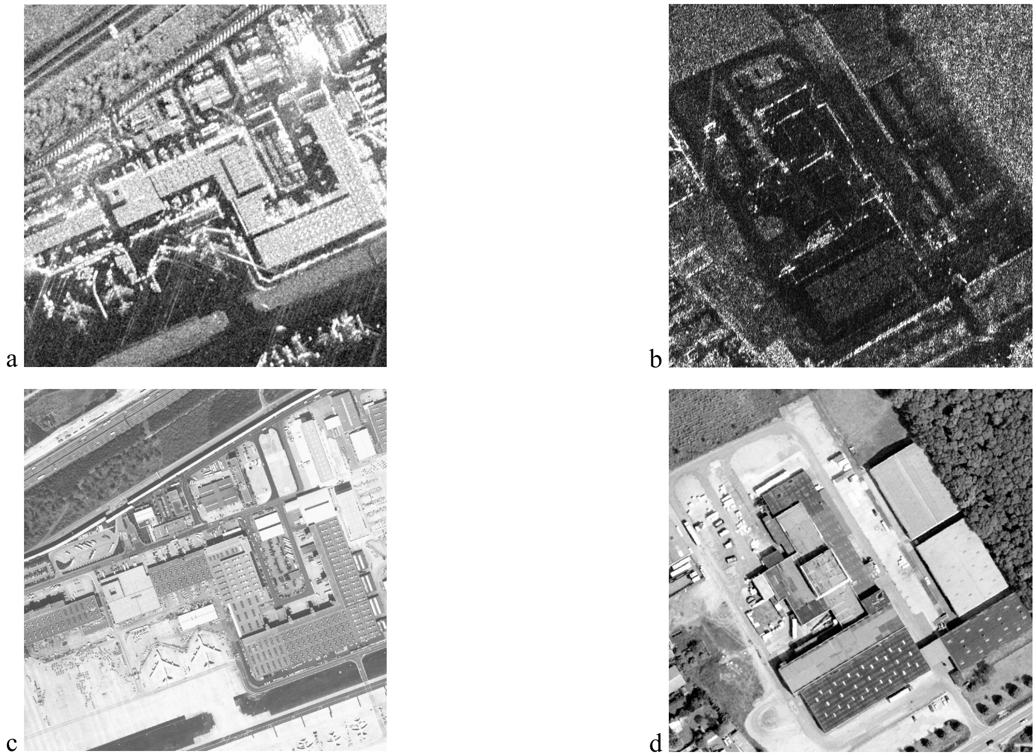
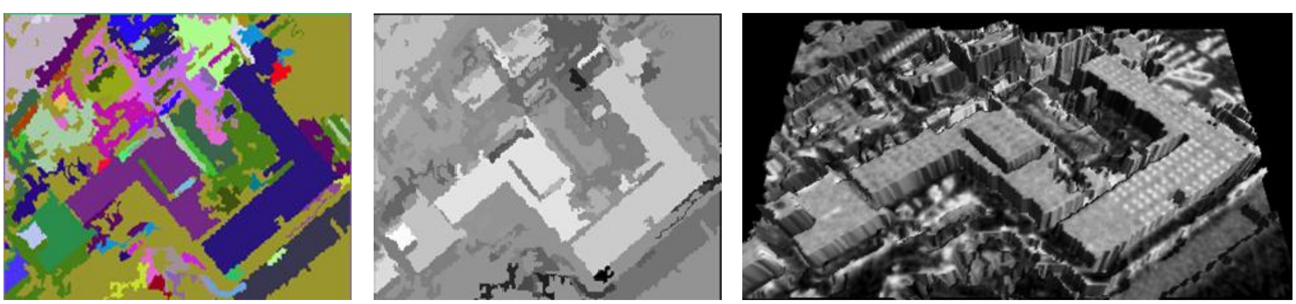


Figure 4 InSAR magnitude image of Frankfurt airport building (a), industrial plant at Dorsten (b) and the corresponding aerial images (c) and (d)

For example, the proposed approach [4] for recognition of industrial halls considers a model-based segmentation of man-made objects in the intensity and the height data. The main assumption of the approach is that locally similar intensity values correspond to regions with equal height information. Closed regions are segmented in the intensity data and the height data on condition that they appear with similar intensity and do not cross intensity edges. In Figure 5 the final results are shown.



a b c

Figure 5 results of approach [4], result of segmentation in intensity image (a), corresponding depth map (b) and 3d-visualisation of recognition result (c)

Applying this reconstruction approach based on segmentation fails here due to the lack of appropriate regions with similar magnitude describing building roofs. Therefore and because of the fact that in high resolution SAR data edges are well detectable as described in [8], the proposed approach in this paper is based on the detection of line structures caused by building edges.

4.1 Algorithm overview

The workflow of the reconstruction process from multi-aspect InSAR data is depicted in Figure 6. The left part shows main steps of common processing of data sets from different flight directions. By contrast the right part displays the sub process, which is individually passed for every data set. This sub processing chain is starting with the formation of the interferometric heights and the magnitude images using the complex data of both antennas. It comprises subpixel registration, followed by the interferogram generation. A flat earth and a phase correction are performed to reduce phase ambiguities at building locations.

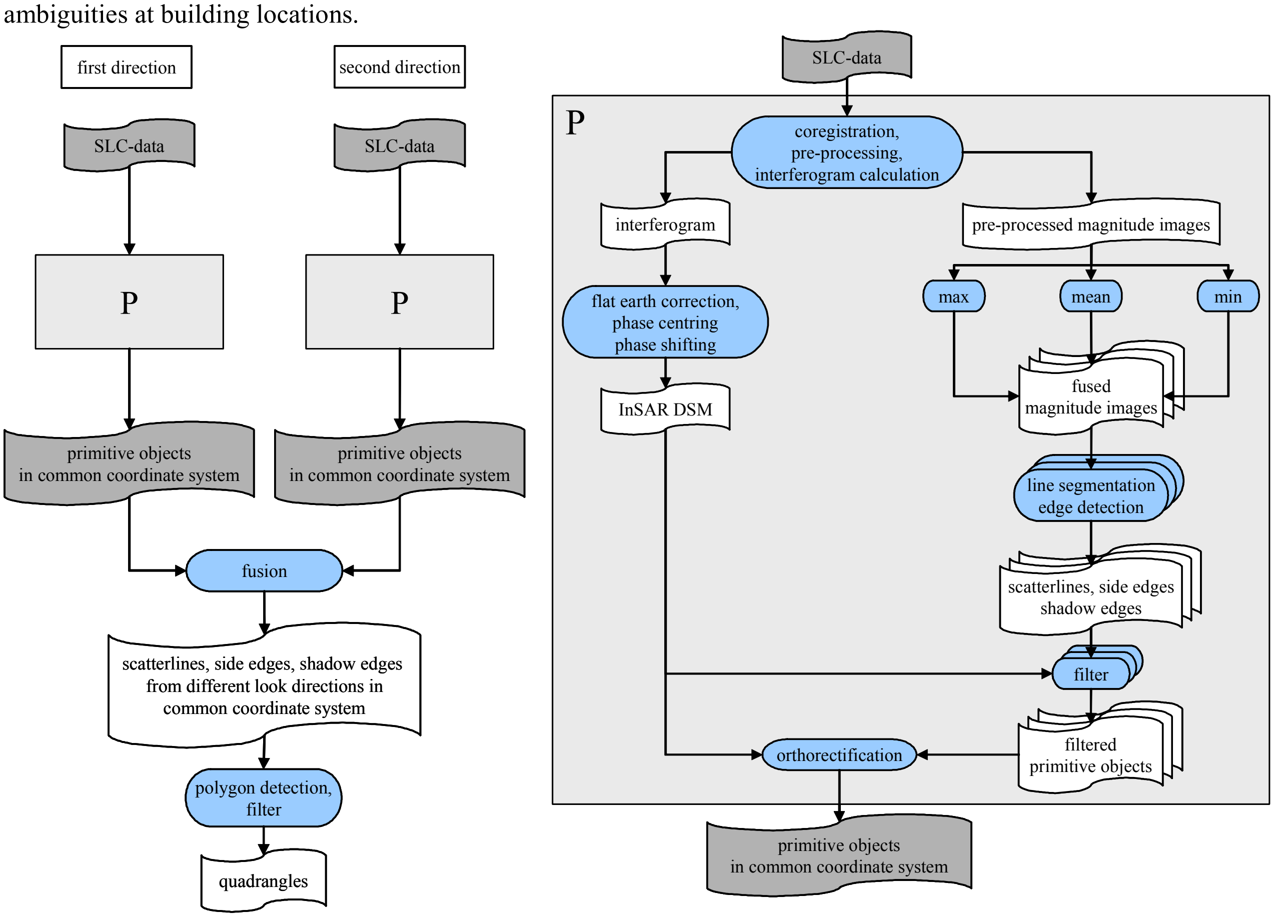


Figure 6 work flow diagram for the reconstruction of buildings from multi-aspect data

The magnitude images are pre-processed (e.g. smoothing and speckle reduction) and fused. The fusion is performed in slant-range applying a maximum, minimum or mean operator. These three methods can be regarded as different forms of multi-look processing of image stacks. Depending on the operator individual features such as shadows or scattering edges can be better distinguished. In the following segmentation step, primitive objects are extracted from the fused magnitude images concerning also the coherence and interferometric heights. The last step of the sub processing chain includes the projection of primitive objects from slant geometry into a common world coordinate system and is individually passed for every data set. Based on fused primitive objects more complex objects (building hypotheses) are assembled in a subsequent segmentation step. To obtain only those building hypotheses (quadrangles), which coincide with real buildings, a filter step considering interferometric heights and coherence is necessary.

4.2. Segmentation of primitive objects in the magnitude images

In the fused magnitude images hints for characteristic structures of man-made objects are searched. These are lines of bright scattering and edges caused by:

- double-bounce reflection (corner) or layover
- building edges
- building shadow

The lines of bright scattering are extracted in the max-fused magnitude image using the Steger-operator [10]. Building edges are detected applying the Canny-operator [11] in the mean-fused magnitude image. A set of edges located at the border of dark regions is extracted from the min-fused magnitude image. An appropriate segmentation step delivers edges including borders at the near side of the region (near shadow edges) with respect to sensor position and at the far side (far shadow edges). In further processing steps the near shadow edges are used for building reconstruction. However, far shadow edges could not be used in the investigation as proposed in [9], because the shadow areas are frequently disturbed by backscattering from close-by vegetation and adjacent buildings.

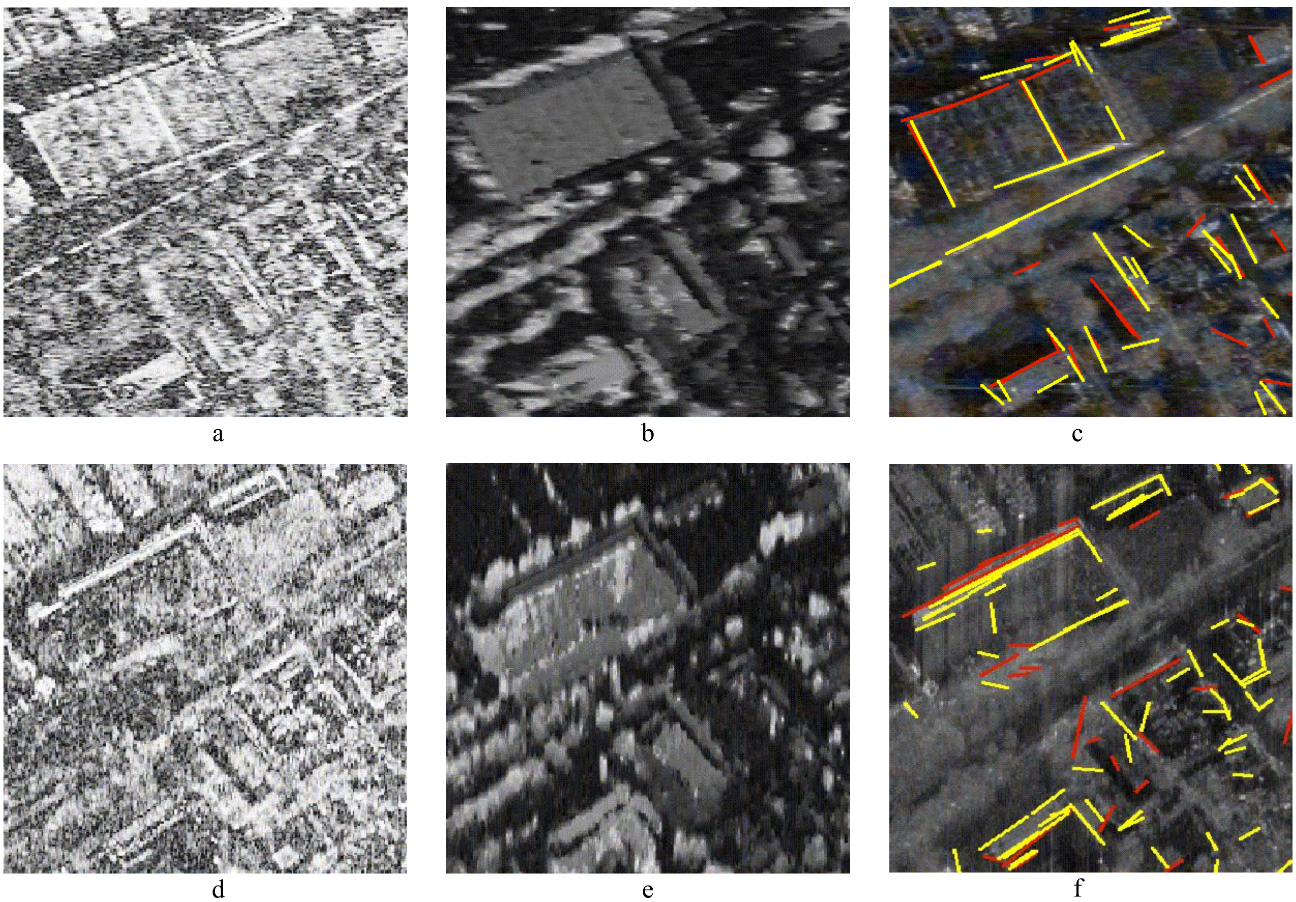
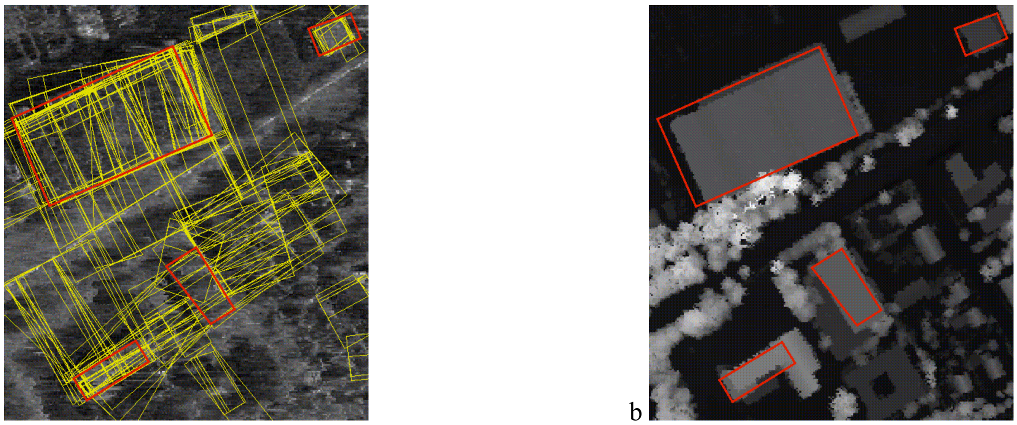


Figure 7 coherence, interferometric heights and detected primitive objects of north-south (a-c) and west-east (d-f) direction

For the extracted edges and lines a set of features is calculated regarding adjacent coherence (Figure 7a,d), heights (b,e) and magnitude values (c,f). These features are used to reduce the amount of primitive objects and to discriminate between near, far and side edges of buildings (yellow and red lines in Figure 7c,d). A straightforward combination of these extracted primitive objects to building hypotheses for each aspect separately often fails. The overlapping effects in the dense built-up areas are too strong. Therefore, a fusion of primitive objects from the different directions is necessary as described in the following section.

4.3 Fusion of primitive objects and detection of building candidates

The InSAR heights are used to project the primitive objects into a common world coordinate system. From the fused primitives, quadrangles are assembled by a production system [9]. At least one edge of the quadrangle facing the sensor must be derived from a line of bright scattering (near edge). Analogous a shadow edge is required at the far edge of the quadrangle. Optionally building side edges are also taken into account. Sets of assembled quadrangles for parts of the scene are shown in Figure 8a and Figure 9a (yellow).



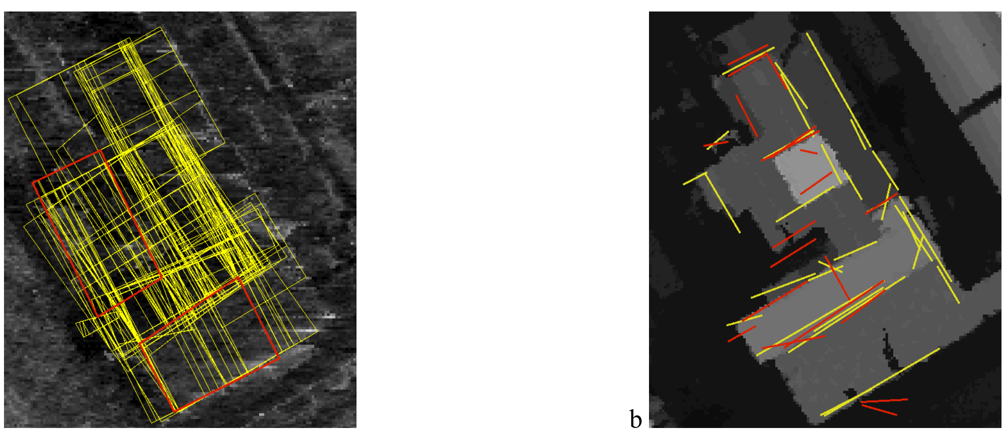
a b

Figure 8 set of assembled objects quadrangle (a), result overlaid with LIDAR-DSM (b)

Only a subset actually coincides with real buildings. To discriminate these corresponding quadrangles from the rest, figures of merit are derived from the coherence, interferometric heights and the relative positioning of the used primitive objects to each other. The remaining objects after the assessment and filtering process are drawn in red.

5. RESULTS AND CONCLUSIONS

With the investigated approach results of different quality for the present data have been achieved. The model-based production system generates results comparable to former results [9] for low-density areas. In Figure 8b the assembled polygons and a LIDAR-DSM (NPA Group) are overlaid for such an area.



a b

Figure 9 set of assembled objects quadrangle (a), detected primitive objects overlaid with LIDAR (b)

For smaller buildings such as one-family houses and more complex building structures the reconstruction process was less successful. This is mainly caused by disturbed InSAR heights in these areas (e.g. due to multipath propagation). This creates displacements of the primitive objects after projection from slant-geometry into the world coordinate system (Figure 9b). Furthermore only few primitive objects were detected for the subsequent building reconstruction.

This seems also to be a consequence of the radiometric properties of the data, because shadow areas are hardly visible, so that shadow edges were scarcely detected.
The application of the approved reconstruction approach [9] to the high-resolution data can not be done without further process adaptations to achieve better results in high-dense urban areas. The above mentioned effects (see section 4.2), which make it difficult to segment far shadow edges are also influencing the segmentation of near shadow edges, but those are necessary for the used polygon detection. In case of having not enough primitive objects, other line constellations like parallel line pairs (see section 3) can be taken into account. Furthermore the impact of look angle variation on primitive objects will be investigated; especially for this data set where off-nadir angle spans a range of 28-52°. It is also necessary to improve the height calculation to enhance the orthorectification results. More process adaptations will be done using simulation results and initial classification to discriminate between buildings, forest and even single trees. Future work will also include an iterative adjustment of the reprojected assembled polygons with the primitive objects in slant geometry.

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