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

Antje Thiele, Ulrich Thoennessen, Erich Cadario and Karsten Schulz, FGAN-FOM Research Institute for Optronics and Pattern Recognition, Germany

Uwe Soergel, Institute of Photogrammetry and GeoInformation, University of Hannover, Germany

### Abstract

The improved ground resolution of state-of-the-art synthetic aperture radar (SAR) sensors suggests utilizing this technique for the 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 difficult from an analysis in a single SAR or InSAR measurement alone. An approach is presented to improve the reconstruction quality combining multi-aspect InSAR data.

Building features are extracted independently for two directions from the magnitude and phase information of the interferometric data. After the 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. Simulation of InSAR data according to the given sensor parameters has supported the analysis of illumination effects and the approach development. 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 a spatial resolution of about 30 cm.

## 1 Introduction

The physical principle of SAR sensors is responsible for specific phenomena [1] like 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 relieved. The detection results are improved by using high-resolution data and a combination of multi-aspect SAR data to compensate partly the interfering illumination effects.

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

## 2 Multi-aspect InSAR Data

The appearance of buildings in multi-aspect highresolution SAR images is discussed using a data set covering a part of the city Dorsten (Germany).



Figure 1 Multi-aspect InSAR magnitude images

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 (X-band). The set of images was taken two times from two flight directions spanning an angle of about 90°, so that from each direction two image pairs were recorded. The overlapping area (see **Figure 1**) covers five square kilometres of an urban area with high building density. Interesting are the mixture of industrial and residential areas, which are characterised by regular groups of buildings with a common alignment in north-south direction and parallel to roads. Furthermore, the dense built-up areas, the high vegetation density, and occlusion by trees interferes the data.

#### 3 Appearance of Buildings in Multi-aspect SAR Images

**Figure 2a,b** illustrates typical SAR illumination effects at flat roofed buildings in the case of orthogonal viewing directions. For comparison the different effects are depicted in simulated (c,e) and processed (d,f) magnitude images for both illumination directions. 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. 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. 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 d) and f). Due to urban density 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, a 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 dense 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**. **Figure 2b** shows the illumination situation for an orthogonal arrangement of the same building. This results in short lines of bright scattering and visible closed roof areas in magnitude images.

Furthermore, frequently observed features are pairs of parallel lines. These bright scatters are caused by gabled roofs orientated perpendicular towards the sen-



**Figure 2** Principal SAR Phenomena at a cubical small and long building. Illumination orientated to long (a) and to short (b) building side. Simulation of SAR Phenomena in flight direction c) north to south, e) west to east. Related magnitude image parts d) and f).

sor. 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 **Figure 2d,f** (green circle), have huge impact on the proposed building reconstruction approach described in the next section.

#### 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 manmade objects can be completely different as shown in **Figure 3**. 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 3** InSAR magnitude image of Frankfurt airport building (ul), industrial plant at Dorsten (ur) and the corresponding aerial images

On the one hand the reconstruction approach [4] based on segmentation in the magnitude and height data fails due to the lack of appropriate regions with similar magnitude describing building roofs. On the other hand in high resolution SAR data edges were well detected as described in [6]. The proposed approach in this paper is based on the detection of line structures caused by building edges.

#### 4.1 Algorithm overview

The 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.

The magnitude images are pre-processed (e.g. smoothing and speckle reduction) and combined. The combination is performed in slant range applying a maximum, minimum or average operator. Depending on the operator individual effects like shadows or scattering edges can be better distinguished. In the following segmentation step, primitive objects are extracted from the combined magnitude images concerning also the coherence and interferometric heights. After projecting these primitive objects from slant into a common world coordinate system, more complex objects (building hypotheses) are assembled in a subsequent segmentation step.

## 4.2 Segmentation of primitive objects in the magnitude images

In the combined magnitude images hints for characteristic structures of man-made objects are searched. These are lines of bright scattering, shadow edges and building side edges. The applied operators are described in [7].



**Figure 4** Interferometric heights and detected primitive objects of north-south (a,c) and west-east (b,d) direction

For the extracted edges and lines a set of features is calculated regarding adjacent heights (Figure 4a,b) and magnitude values. These features are used to discriminate between near, far and side edges (yellow and red lines in Figure 4c,d). A straightforward combination of these extracted primitive objects to building hypotheses for each aspect separately fails. The overlapping effects in the dense built-up areas are too strong.

# 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 [7]. 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. Set of assembled quadrangles for a part of the scene is shown in **Figure 5** (yellow).



**Figure 5** Set of assembled objects quadrangle (l.), result overlaid with LIDAR-DSM (r.)

Only a subset actually coincides with real buildings. To discriminate these corresponding quadrangles from the rest, figures of merit are derived from the coherence and interferometric heights. The remaining objects after the assessment 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 [7] for low-density areas. In **Figure 5** (r.) the assembled polygons and a LIDAR-DSM (NPA Group) are overlaid for such an area.



**Figure 6** Set of assembled objects quadrangle (l.), detected primitive objects overlaid with LIDAR (r.)

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 slantgeometry into the world coordinate system (**Figure 6** r.). Furthermore only a few primitive objects were detected for the subsequent building reconstruction. This seems also to be an attribute to 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 [7] to the high-resolution data can not be done without further process adaptations to achieve better results in high-dense urban areas. It is necessary to improve the height calculation and to adapt the investigated model-based reconstruction approach. For this purpose the simulation results and an adjustment of the reprojected assembled polygons with the primitive objects in slant geometry is the starting point for the future adaptations.

### References

- Schreier, G. : Geometrical Properties of SAR Images. In: Schreier G. (ed) SAR Geocoding: Data and Systems. Karlsruhe: Wichmann, 1993, pp. 103-134
- [2] Gamba, P., Houshmand, B., and Saccini, M.: Detection and Extraction of Buildings from Interferometric SAR Data. IEEE Transactions on Geoscience and Remote Sensing. Vol. 38, No.1, 2000, pp. 611-618
- [3] Bolter, R.: Buildings from SAR: Detection and Re-construction of Buildings from Multiple View High Resolution Interferometric SAR Data. University Graz: Phd. Thesis, 2001
- [4] Soergel, U., Schulz, K., and Thoennessen, U.: Phenomenology-based Segmentation of InSAR Data for Building Detection. In: Radig, B., Florczyk, S. (eds) Pattern Recognition: 23<sup>rd</sup> DAGM Symposium. Springer, 2001, pp. 345-352
- [5] Schwaebisch, M. and Moreira, J.: The High Resolution Airborne Interferometric SAR AeS-1. In: Proceedings of the Fourth International Airborne Remote Sensing Conference and Exhibition, Ottawa, Canada, 1999, pp. 540-547
- [6] Soergel, U., Thoennessen, U., Stilla, U. and Brenner, A.: New Opportunities and Challenges for Analysis of Urban Areas in High-resolution SAR Data. Proc. Of 5<sup>th</sup> European conference on synthetic aperture radar, EUSAR 2004, pp. 416-418
- [7] Soergel, U., Thoennessen, U. and Stilla, U.: Iterative Building Reconstruction in Multi-Aspect InSAR Data. In: Maas HG, Vosselman G, Streilein A (eds) 3-D Reconstruction from Airborne Laserscanner and InSAR Data, International Archives of Photogrammetry and Remote Sensing, Vol. 34, Part 3/W13, pp. 186-192