Modelling and Analysing InSAR Phase Profiles at Building Locations in Multi-Aspect and Multi-Resolution Data

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Abstract

The improved ground resolution of state-of-the-art synthetic aperture radar (SAR) sensors suggests utilizing SAR data for the analysis of urban areas. Even in the case of multi-aspect InSAR, for building recognition usually the analysis is triggered mainly from features detected in the magnitude images and the benefit of fusing different views. However, considering InSAR data significant phase profiles in range direction at building locations are observable, caused by information mixture of the building and its surrounding area. Hence, it is worthwhile to make efforts to understand such phase variations to improve the building recognition, especially in the case of multi-aspect, multi-sensor and multi-temporal data.
In this paper three InSAR data sets of the airborne sensors AeS-1 and STAR-3i (Intermap Technologies) with a slant range resolution of 38 cm respectively 1 m are investigated. Two of them are used to reconstruct initial building hypotheses based on our previous approach. Given these 3D models, the simulation of phase profiles at the building location is realized considering the specific sensor and illumination parameters of the data sets. According to the multi-aspect and multi-resolution configurations, changes in the phase distribution are observable. Subsequently, an assessment between the real and simulated phases is done and the potentials of considering these effects in the building recognition process are discussed.

1 Introduction

The detection and reconstruction of buildings from SAR data is mostly driven by analysis of magnitude images focussing on effects [1] caused by the inherent oblique scene illumination. By a combined analysis of multi-aspect data a significant improvement of the recognition results were shown in [2] and [3]. If InSAR data are provided, they are additionally used for height estimation of the building hypotheses. The difficulty is to extract the most reliable height information from different data. Hence, the analyzing of the InSAR phases is necessary, and was studied especially at building locations in [4] and [5]. For a detailed analysis of phase variations, caused by sensor and building model parameters, a simulation model was implemented [6]. Hence, it has to be determined whether this phase information can improve the results of building reconstruction, especially by considering multi-aspect, multi-sensor and multi-temporal data in the process.
This paper is organized as follows: In Chapter 2 the investigated InSAR data sets are introduced. Our approach of building reconstruction is presented in Chapter 3, focusing on the steps of interferogram calculation and hypothesis assembling. Chapter 4 and 5 show the subsequent steps of phase simulation as well as the comparison between the real and the simulated interferometric phases. The conclusion is given in Chapter 6.

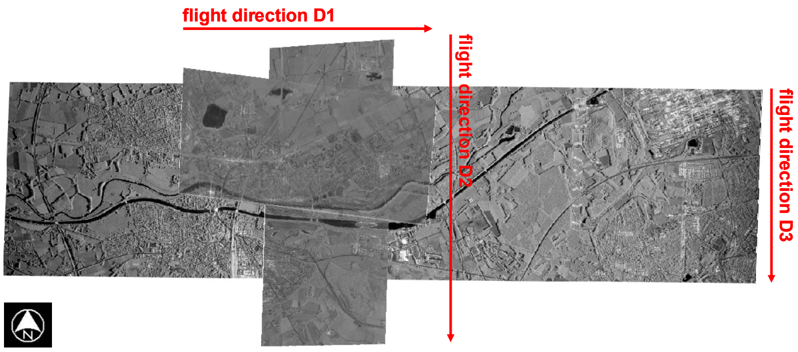
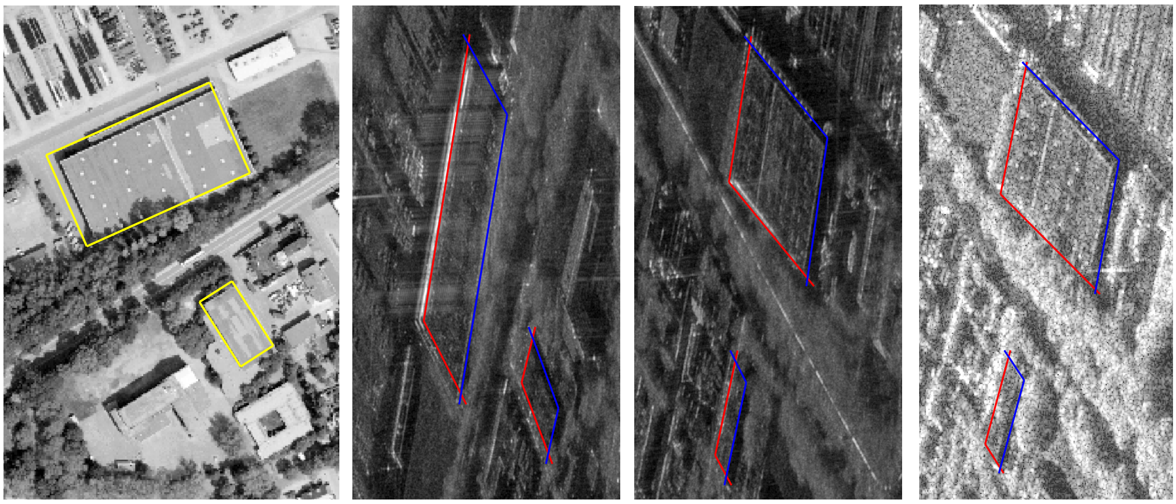


Figure 1 Ground projection of the magnitude images of the three InSAR data sets



a b c d

Figure 2 Orthophoto overlaid by results of the building reconstruction (a), magnitude images overlaid by re-projected building footprints of D1 (b), D2 (c) and D3 (d); sensor close (red) and sensor far (blue) footprint lines

2 InSAR Data sets

For this study three data sets acquired from the Intermap Technologies company are investigated. The SAR data sets, covering a part of the city Dorsten (Germany), were recorded by two different sensor systems using an interferometric antenna configuration.
The high-resolution airborne sensor Aes-1 [7] was operating in X-band at 3000 m flight height with a spatial resolution of about 38 cm in range and 17 cm in azimuth direction. The baseline was about 2.4 m and the scene was illuminated with an off-nadir angle θ spanning a range from 28° up to 52°. With this sensor SAR data were taken twice from orthogonal viewing directions, thereby the first flight direction (D1) is west-east and the second (D2) north-south oriented. The two stripes show a size of 2 by 5 km with an overlapping area of 4 square kilometres.
The third stripe (D3) was taken by the airborne sensor Star-3i [8]. This X-band sensor was operating in a flight height of 8500 m with a baseline of 0.9 m. The pixel spacing in slant range geometry is 1 m in range and 0.5 m in azimuth direction. The stripe has a size of 3.5 by 14 km and shows an off-nadir angle varying from 26° to 66°. The flight track (D3) corresponds to north-south direction. Accordingly, the stripes D2 and D3 span up only an angle of 5 degree. The geometric alignment and the overlapping area between all three stripes in ground range geometry are given in **Figure 1**.

3 Reconstruction of Buildings

Our approach of building reconstruction exploits the SAR phenomena at building locations (layover, corner line, roof signature and shadow area) and benefits from the analysis of multi-aspect data, especially from orthogonal views.

3.1 Interferogram Calculation

The interferogram generation is a pre-processing step of the building reconstruction approach and necessary for the validation of the phase simulation as well.
The calculation includes a multi-look filtering and is followed by the steps of flat earth compensation, phase centering and phase correction. With the phase centering a phase distribution with zero mean can be achieved. The additional step of phase shifting is integrated in the conversion from phase differences into terrain heights [3]. This contains a phase shifting upwards by 2 π for all phase values significantly below a threshold to overcome a suboptimal choice of the elevation interval borders.
The final interferometric phases and heights of an industrial hall are shown in **Figure 3 a,b**.

3.2 Assembling of Buildings

The process of building reconstruction presented in [3] based on multi-aspect InSAR data. In the slant range magnitude images primitives are extracted, exploiting SAR phenomena at building locations such as layover, corner line, roof signature and shadow area. Therefore, the Steger-Operator [9], the Canny-Operator [10], and a dark region segmentation step are used. The resulting primitives, which correspond to building front, side and back footprint lines, are projected in the ground geometry by using the interferometric height data. In the common coordinate system the fusion of primitives of different aspects is possible. Additionally, based on all primitives building hypotheses are assembled by a rule-based production

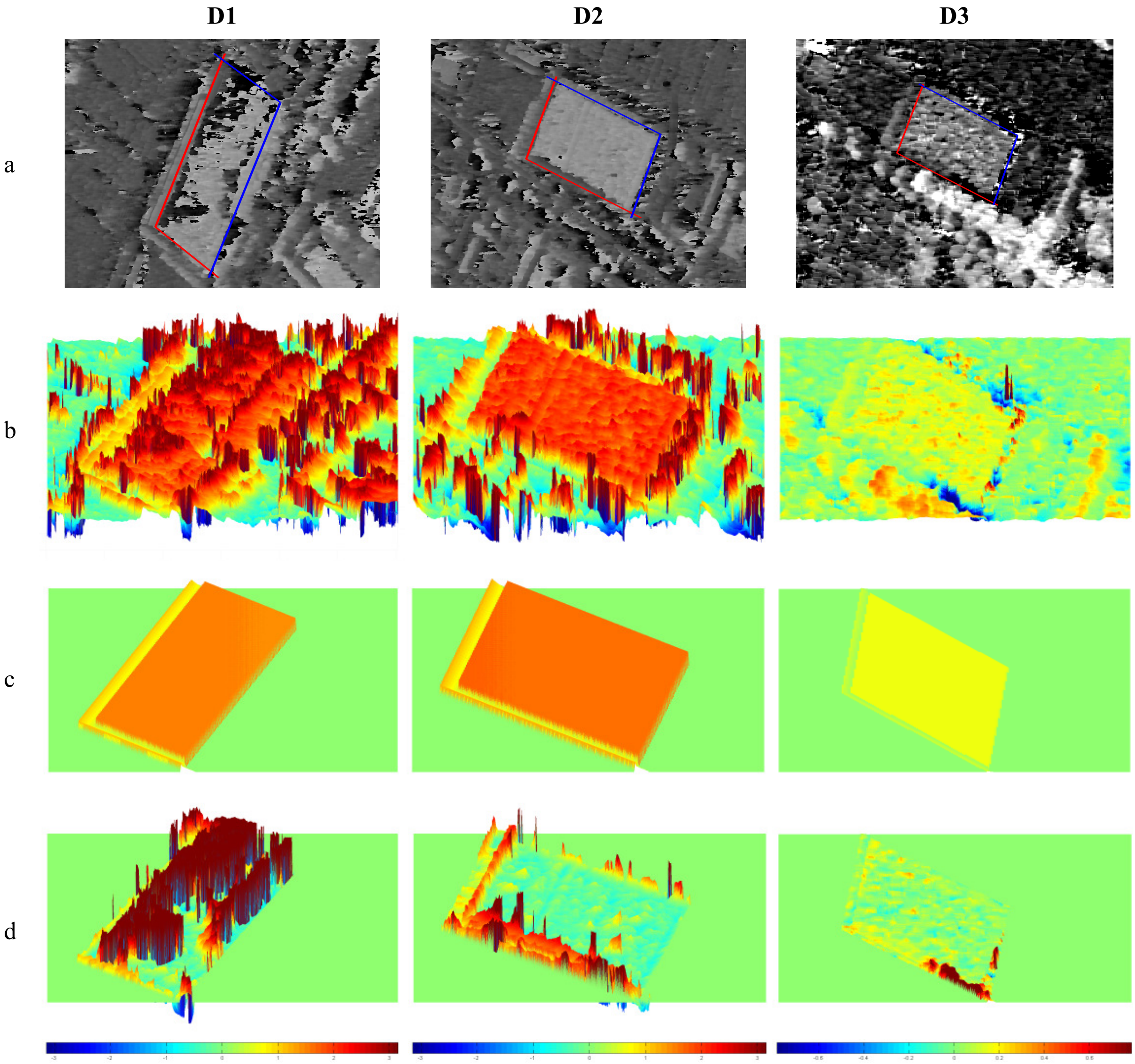


Figure 3 Interferomertic heights in slant range overlaid with re-projected building footprint (a), 3D visualization of real interferometric phases (b), of simulated phases (c), and differences between real and simulated phases

system. The final right angled footprints based on the data sets D1 and D2 are given in **Figure 2a**.

For an assessment of the height information of the different data sets it is useful to project the final building footprint from the ground geometry back into the slant geometry. With respect to the SAR mapping geometry, this projection has to be done by considering two different heights. Normally, we have two sensor close footprint lines (marked in red), neglecting the case of parallel building orientation and flight direction, where is only one line. These lines correspond to the corner lines in the images and have to be projected by a mean local terrain height. The two or three sensor far footprint lines (marked in blue) are located between roof signature and shadow area. These lines obtain the reconstructed building height as projection feature. The resulting building footprints re-projected in the slant range geometry of the different aspects are depicted in **Figure 2b,c,d**. Based on these footprints a validation of same time data as well as change detection in time series is possible.

4 Simulation of InSAR Phases

Our process of phase profile simulation [6] is based on the assembled building hypotheses and the extracted mean building height from the interferometic height data [3].

The phase profile simulation starts with the definition of the sensor parameters, e.g. wavelength, sensor altitude, antenna configuration, slant range resolution. The given building model is split up in ground range cells. For each of these ground cells the corresponding range cell is determined and the quantities local incidence angle, normal vector, range distance difference, and phase difference are calculated [6].

The subsequent simulation is carried out according to the slant range grid of the InSAR data. For the purpose of assessment between simulated and real measured phases, the different azimuth and range resolution of the investigated InSAR data have to be considered.

The resulting interferometric phase of one range cell is calculated by summing up all contributions (e.g. from ground, wall and roof). Furthermore, the process of phase profile simulation includes detection of shadow areas, and flat earth correction. The shadow areas are modelled to coincide with areas of zero reflection; noise impact is not considered here. The simulation results of the industrial hall specified by the sensor configuration of the investigated multi-aspect and multi-resolution data sets are given in **Figure 3 c**.

5 Comparison

The assessment of real and simulated InSAR phases is shown on an industrial hall (**Figure 3**). The reconstruction process based on multi-aspect data delivered a building hypothesis of 58 x 105 x 7.5 m. In comparison ground truth data show a building extension of 50 x 100 x 8.6 m.

The result of phase simulation considering the reconstruction result is given for all three data sets in **Figure 3c**. The differences are caused by a rising 2π height ambiguity limit, due to the special sensor and illumination parameters of the data sets. To overcome this visualisation problem the phase scaling of D3 is adapted. The subsequent assessment focused on the differences (**Figure 3d**) as well as the correlation between the real and simulated phases. The highest correlation value of about 0.5 could be achieved for the data set D2, which matches with the depicted difference diagram. Following the phase information of D2 is the most reliable one for the final building height estimation.

In further research we will present possibilities for improving the building reconstruction results by this step of phase adjustment [11]. Furthermore, the benefit of this phase assessment for the task of change detection has to be analysed, especially in case of detecting extended or destroyed buildings.

6 Conclusion

In this paper an approach was presented to reconstruct buildings from multi-aspect data by combing the structural approach with the phase simulation approach. Therefore, three multi-aspect, multi-resolution and multi-temporal InSAR data sets were investigated. As a result of the assessment between real and simulated phases the most reliable phase information for the building height estimation was detected. How this analysis of InSAR phases can be best exploited in the building reconstruction approach and in the task of change detection is part of further investigations.

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