PHENOMENOLOGY-BASED AND INTERFEROMETRY-GUIDED BUILDING RECONSTRUCTION FROM MULTIPLE SAR IMAGES

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ABSTRACT

The aim of our work is the reconstruction of the structure of building ensembles from high resolution interferometric and slant range SAR data. To fully automate the building reconstruction procedure we want to use a phenomenological approach, using layover and shadow boundaries together with edge information and intelligent combinations of measurements from all IFSAR data sources available. In this paper we focus on the phenomenology and geometry of interferometric SAR measurements from buildings. Therefore we created a work environment with a simulator to produce single pass interferometric SAR data. We use this simulated data to study the phenomenology and geometry of interferometric measurements of simple building models and compare our findings with real interferometric data from the MOUT testsite. A simple fusion scheme for multiple interferometric SAR images is obtained from simulated data and applied to original data.

1 INTRODUCTION

SAR imagery has begun to get consideration as a source for three-dimensional building models [3]. High resolutions at pixel sizes of 30 cm to 10 cm and single pass interferometry support the geometric reconstruction of various small man-made objects. Interferometrically derived digital elevation models are usually less detailed than the basic magnitude images, and suffer from effects of blur, speckle, layover and shadows. To better understand these phenomenological features, we developed a simulator to produce interferometric height data. In this paper we present our overall strategy for building detection and reconstruction from multiple interferometric SAR data. The interferometry simulator is described in more detail and the resulting simulated images are compared to actual high resolution interferometric data. Therefrom a simple fusion scheme for multiple view interferometric data is obtained.

Extraction of man-made objects from optical imagery is a lively topic in the remote sensing community. Recent demonstrations from high resolution SAR data were based on manual work, some limited automated methods can be found. In [10] fusion of IFSAR and multispectral optical image data results in boundary boxes of buildings. [6] describes an automatic region growing approach to localize buildings starting from the shadows they cast. The reconstruction of building shapes of urban tower blocks from IFSAR data by applying a range segmentation algorithm is presented in [4]. In [2] Geometrical considerations of the interferometric imaging process lead to an approach to enhance the quality of IFSAR height measurements. All these previous demonstrations are performed on single type data. We want to employ the best source available for each single measurement and combine the results in an intelligent way.

2 CONCEPT

In contrast to optical sensors, modern high resolution interferometric SAR sensors deliver intensity images and corresponding interferometric height and coherence data from a single flight path. Due to the all-weather, day-night applicability of IFSAR sensors, multiple views over a short time can be easily obtained. The data sources have two dimensions of multiplicity: one is multiple data types, the other is multiple views. The synergy between these two types of multiplicities is expected to resolve ambiguities present in single view, single type data. For example, layover, shadow and occlusion phenomena manifest themself perpendicular to the sensor flight path in each single data source. Combining single measurements from two opposite views or from four cardinal azimuth directions may help to overcome these problems.

All these mentioned effects in interferometric SAR measurements depend highly on the geometric image and scene properties. To study these effects and their dependence on the geometric parameters in detail, we set up a work environment with a single pass IFSAR simulator. From simulated data the information contained in each single data type is exploited and from single data type, multiple view simulated data the underlying scene geometry is reconstructed . Afterwards the results from single data type measurements are fused. The same procedures are applied to original SAR data and the results are compared to ground truth data obtained from optical imagery. Feeding the results back into the simulator and compare the simulations to the actual data could establish a feedback loop to further enhance to process.

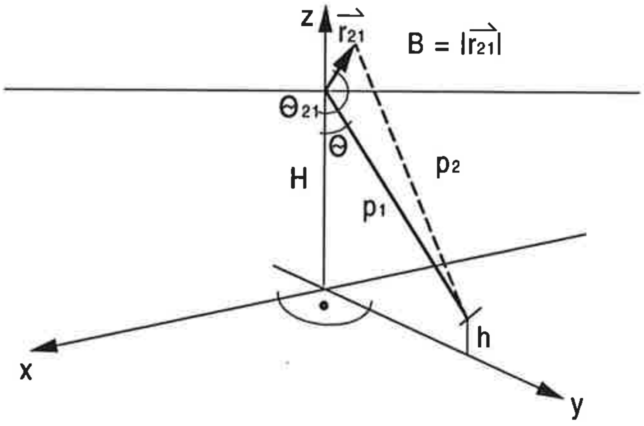
Original image test data are used from the MOUT testsite (USA) imaged from four cardinal azimuth directions with a Sandia Spotlight IFSAR sensor. The buildings on this site are clustered in a compact group resembling a northern European village, surrounded by undeveloped land. Each Spotlight pass was processed into four channels: magnitude, correlation, height and bin number, and converted to UTM coordinates. The original slant range magnitude images are also available.

Our slant range magnitude SAR simulator and the reconstruction of a single building from slant range SAR shadows is presented in [1]. The extension of our simulator to produce high resolution interferometric height measurements is described in more detail in this paper.

3 IFSAR SIMULATION

A considerably body of literature on the topic of SAR image simulation can be found. The basic principles are described in [7]. A simulator for various spaceborne and airborne sensors is presented in [5]. The use of simulated interferometric SAR data was only addressed once in the context of modeling the statistics in layover areas [9].

An overview of the SAR interferometric principles can be found in [8]. SAR interferometry is fundamentally different from optical interferometry as the phase of the complex signal is directly measurable. Two classes of IFSAR sensors used for topographic mapping are used: single pass type sensor, where two (or more) antennas are mounted on the same platform and simultaneously image the scene, or the two pass type where separate passes of a single antenna sensor over the same target are used to form the interferogram. The test data available for our experiments are of the single pass type, therefore we implemented a single pass type sensor for our simulator with a simplified geometric situation, where the SAR antenna fan beam is oriented perpendicular to the platform path, and the data are processed to ensure that the radar "looks" in a direction orthogonal to the platform velocity vector. The basic across-track interferometer geometry can be seen from Figure 1. The main antenna transmits pulses and the magnitude and phase of the reflected signals are recorded on both antennas. From the phase difference between the two antenna, the corresponding terrain height can be recovered [8].



δJ *Across-track interferometer geometry. The platform is flying parallel to the x-axis at an elevation of H. The baseline vector is* ${}_{12}$*, and the orientation is defined by the angle* θ_{21} *(after [8].*

As stated previously, the simulation of interferometric height data is an extension to our already existing slant range magnitude SAR image simulator [1]. In this simulator we start from a high resolution digital elevation model (DEM) in Cartesian coordinates and a straight flight path perpendicular to the DEM. The SAR slant range images are calculated line by line as follows. For each range bin of the resulting SAR image the whole DEM line profile is checked from left to right. The range line of length r (corresponding to the range bin in the final image) is intersected with the straight line connecting two adjacent points in the DEM line profile. If an intersection is reported, the corresponding backscatter value is calculated from the local incidence angle and stored in the appropriate range bin of the final magnitude image. In case of layover, when more than one point of the terrain is imaged by the sensor at the same time, the backscatter values in the corresponding range bin sum up, thereby ensuring that layover is automatically considered in the appropriate way.

To decide, if a target point found by the range intersection algorithm lies in radar shadow, the maximum look angle and the column of the DEM point imaged under this look angle are stored during the range intersection process. If the actual look angle of a new target point is lower than the actual maximum look angle, the backscatter value of the new target point is only added to the backscatter sum of the corresponding range bin, if the column is lower than the stored maximum column.

Speckle effects result from the need to create the radar image with coherent radiation. In this study we are mainly concerned with geometrical aspects of IFSAR sensors, therefore SAR signals are treated as coherent waves, instead of random variables. To achieve an appearance similar to real images for our simulated images we model the DEM as optically rough surface, normal random noise is added to each pixel in the input DEM.

The calculation of the phase information, necessary for an interferometry simulator, starts after the shadow decision procedure. For each radar hit in the terrain the distances to both antenna positions can be calculated from the actual geometry as seen from Figure 1.

$$1 \qquad \frac{\pi}{\lambda}\sqrt{\qquad - \qquad {}^{2} \qquad {}^{2}} \qquad (1)$$

$$2 \qquad \frac{\pi}{\lambda}\sqrt{\qquad ' - \qquad {}^{2} \qquad {}^{\prime 2}} \qquad (2)$$

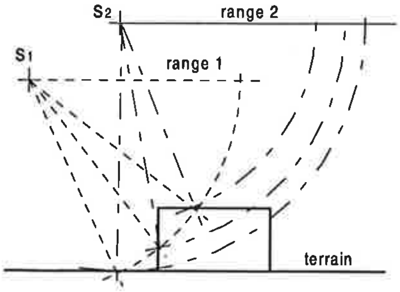
with

$$' \qquad\qquad \theta_{21} - \frac{\pi}{\ } \qquad (3)$$

$$' \qquad - \qquad \theta_{21} - \frac{\pi}{\ } \qquad (4)$$

The resulting phase difference is stored. Because of the known terrain topography in case of simulation the absolute phase difference between the two antennas can be calculated in contrast to the π periodic relative phase measured from a real interferometric SAR system. This simplifies the interferometric processing, phase unwrapping is unnecessary.

In shadow areas, no radar signal response occurs, therefore no phase difference has to be calculated. The proper consideration of layover areas needs more attention. In case of layover, more than one point on the terrain is hit by the radar signal at the same time. The distance from these points back to the main antenna is equal for all points, the resulting signal phase can be computed from this joint range value. However, the distances between these target points and the second antenna differ, as can be seen from Figure 2. The signal received by the second antenna is a superposition of waves reflected from the targets on the ground. To calculate the resulting phase for the second antenna in our simulator, phase and intensity information for each single contribution is stored and the superposition of this single waves is calculated in case of layover.



2 J *Layover and interferometry (not to scale): the range distance to the main antenna* $_1$ *is the same for all points affected from layover, the distance to the second antenna* $_2$ *differs for these points.*

Due to this superposition of single waves in layover areas, the transition from the phase on the ground to the phase on an objects top is not smooth, the phase difference oscillates between these two values. The results of this effect on the interferometric height will be discussed in the next chapter.

What remains to be solved for the simulator is the phase to height conversion. As stated previously, due to the knowledge of the exact geometry, the absolute phase difference is stored, therefore we are not concerned with phase unwrapping. The derivation for the phase to height conversion formulas can be found in e.g. [8]. For each entry in the simulated phase difference matrix ϕ a corresponding height and y-position value can be calculated:

$$\theta \quad \theta_{21} - \frac{\pi}{\ } - \qquad \frac{\lambda\phi}{\pi B} \tag{5}$$

$$- \ _1 \quad \theta \tag{6}$$

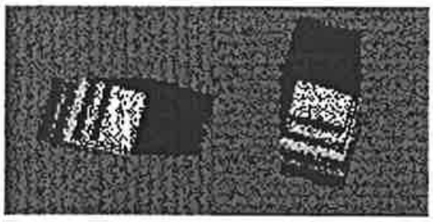
$$_1 \quad \theta \tag{7}$$

The resulting height values are stored in an array according to the respective Y-position. Simulation results for a simple building model are presented in the next chapter.

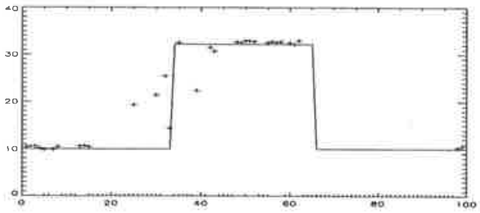
4 IFSAR SIMULATION RESULTS

The digital elevation model of a simple rectangular building with a flat roof was input to our simulator. The simulation results for the interferometric height for two different views can be seen from the left of Figure 3. The DEM was imaged from the left for the left image in Figure 3 and from the bottom for the right image in Figure 3. Figure 4 shows a profile trough the height image on the left of Figure 3 with the original elevation overlaid.

The height measurements on the buildings top correspond to the elevation only on the backside of the roof, as seen from the sensor, the front side of the roof and the area around the buildings front wall is severely disturbed due to layover effects. The resulting height values in the layover area are in between the height values on the ground and the height values on the objects top. This results from the superposition of multiple scatterers in layover areas. This effect is already described in [2] for original interferometric SAR data. The effect is denoted as front porch effect, appearing as an extended region on the near-range side of the building that is characterized by elevations in between ground level and the elevation at the building's top.



3 J *Simulated interferometric height for a rectangular flat roofed building imaged from the left (left) and from bottom (right). The pixel size is 0.3m.*



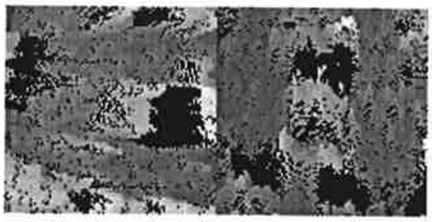
4 J *Profile of interferometric height measurements (crosses) for a simple building model extracted from the horizontal center line from the left image in Figure 3 with overlaid input DEM profile (solid line).*

5 COMPARISON WITH ORIGINAL DATA

Figure 5 shows a section from the original Sandia Spotlight interferometric height measurements from our testsite. The imaged building has the same dimensions as in our simulation, the flight path corresponds with our simulated flight path. This original data is more severely affected by noise and blur effects than the corresponding simulated images from Figure 3. However, the phenomenology of front porch, roof and shadow area corresponds with the simulation in Figure 3.

6 FUSION OF MULTIPLE VIEWS

From the simulation we learned that the interferometric height measurements from a single view conform with the actual data only on the far range side. Especially due to layover the height measurements inside the building area are lower or equal than the actual data, but never exceed the building's height. The so called front porch is located in an area outside the building on the near range side of the building. In this area the height measurements exceed the



5 J *Subscene of original interferometric height data showing a rectangular flat roofed building from two different views, imaged from the left (on the left) and from bottom (right) with a Sandia Spotlight IFSAR sensor. The pixel size in the images is 0.3m.*

6 J *Maximum fusion of interferometric height data from four independet views for simulated data (left), applied to original data (middle) and fusion of original data according to maximum correlation (right). Pixel size is 0.3m*

actual data. A single view interferometric digital elevation model seems not suitable for building detection and especially reconstruction. The combination of multiple views of interferometric DEMs helps to enhance the usability of the data.

For the fusion of multiple view interferometric height data in [10] the correlation channel of the interferometric dataset was used. For each pixel the DEM that had the highest correlation value for that pixel was chosen and the elevation was used in the combined DEM. This procedure seems feasible because the correlation is usually worse in layover areas, however, due to the insight gained from the simulation, we propose a different scheme.

Because inside the building area the interferometric height measurements are just lower or equal than the actual data we propose a simple maximum fusion scheme, for each pixel in the final DEM the maximum height value from the independent measurements is chosen. For simulated data the result of this maximum fusion scheme can be seen from the left of Figure 6. Four independent simulations from four cardinal azimuth views were generated and for each pixel in the resulting DEM the maximum height value from the four independent views was chosen. The roof area corresponds highly with the DEM which was input to the simulator, only in a small area around the building the front porch is present. However, in contrast to the original single view, this resulting DEM seem much more useful for building detection and reconstruction.

The same fusion scheme was applied to original Spotlight IFSAR data, the four independent views were combined using the maximum fusion scheme. The result can be seen from the middle image in Figure 6. The roof area seems quite homogeneous compared to the single views, however due to the front porch, speckle and blur effects the building's outlines are fuzzy. Figure 6 shows on the right the result of applying the maximum correlation fusion scheme. At each position in the image the height value with the maximum corresponding correlation value is chosen. Compared to the maximum fusion scheme, significant height variations in the roof area occur.

7 DISCUSSION AND OUTLOOK

In this paper we have presented our concept for building reconstruction from interferometric SAR data. Our simulator to produce interferometric SAR height measurements was described in detail. The simulation results of a simple building model were discussed and compared to actual data. A simple maximum fusion scheme was presented. Although due to the front porch effect, this maximum fusion scheme results in enlarged building areas, the height values inside the actual roof areas are enhanced, the enlarged buildings outline will ease the next step in the building reconstruction attempt, the detection and localization of buildings from this fused DEM.

8 REFERENCES

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