

UTILIZATION OF LIDAR DEM FOR SAR IMAGE ANALYSIS IN DENSE URBAN AREAS

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ABSTRACT:

The increasing resolution of SAR data opens the possibility to utilise this data for scene interpretation in urban areas. Different SAR specific phenomena like foreshortening, layover, shadow and multipath-propagation burden the interpretation. For many urban areas detailed additional information is available which can support both the mission planning and the analysis of the acquired SAR data afterwards. In this paper a high resolution LIDAR DEM is incorporated to investigate the impact of the phenomena on the visibility of scene objects by a SAR measurement from a given sensor trajectory and orientation in an urban environment. This kind of ground truth is well suited for this task because it contains elevation information of every object in the scene. Shadow and layover areas are simulated by incoherent sampling of the DEM. By a variation of viewing and aspect angles a large number of such simulations are carried out. From this set of segmentations the n best are determined according to two example tasks, namely the analysis of objects on roads and the detection and reconstruction of buildings. The locations of the roads and the buildings are extracted from a GIS.

1. INTRODUCTION

The side-looking illumination of SAR causes phenomena like foreshortening, layover and shadow at elevated objects in the scene (Schreier, 1993). Due to the mostly vertical walls these phenomena occur always at building locations. Especially in dense urban areas large parts of the scene can be interfered by the phenomena. This may hinder the analysis of SAR images, particularly by automatic pattern recognition methods.

Knowledge about the scene is required for the mission planning and the analysis of the acquired SAR data. In the mission planning phase the flight path and illumination direction should be optimised with respect to the visibility of the area of interest. The possible benefit from the exploitation of different types of information will be discussed in the context of two example tasks, namely the analysis of objects on roads and the detection and reconstruction of buildings (Bolter, 2000; Soergel et al. 2000; Stilla et al., 2001).

Nowadays, scene knowledge is often represented in thematic layers of a vector map in a geographic information system (GIS). In this paper the road and the building layer are considered for the analysis.

The incorporation of elevation data in mission planning, geocoding and analysis of SAR imagery is investigated for many years (Gelautz et al., 1998). However, in the past often coarse digital terrain models (DTM) were available only (e.g. 30 m). This ground resolution was sufficient for geocoding and interpretation of satellite SAR data. Approaches for the simulation of layover and shadow areas from a given DTM were proposed in the literature for satellite data and rural scenes (Meier et al., 1993). The layover and shadow regions are identified by incoherent sampling of the elevation data from a given sensor trajectory. Furthermore, the DTM was incorporated to simulate the influence of the terrain slope on a SAR measurement.

The increasing resolution of new SAR sensor systems give rise for the need of more precise elevation data. In urban areas CAD building descriptions have been used as ground truth for a

simulation of layover and shadow areas (Bolter, 2000). But CAD data sets are often restricted to man-made objects. In order to avoid too optimistic estimations of the visibility of man-made objects the influence of natural objects like trees should be considered in urban areas as well. Such objects are e.g. represented in high resolution digital elevation models (DEM) derived from LIDAR measurements.

In Chapter 2 geometric constraints of the visibility of buildings and roads in SAR data are derived. A high resolution SAR image of the campus of the University of Karlsruhe (Germany) and surrounding inner city area is analysed in Chapter 3. For this task 2D vector maps and a high resolution LIDAR DEM (Fig. 1) of the scene are incorporated (Sec. 3.1). From the DEM layover and shadow maps are calculated incoherently to determine the visibility of roads and building roofs, assuming a special viewing angle and flight track (Sec. 3.2). This simulation is carried out for a large number of different aspect and viewing angles. The optimal combinations for two, three and four SAR images are determined (Sec 3.3). In Chapter 4 the extension of the approach towards a detection of possible locations of multi-propagation and total reflection is discussed.

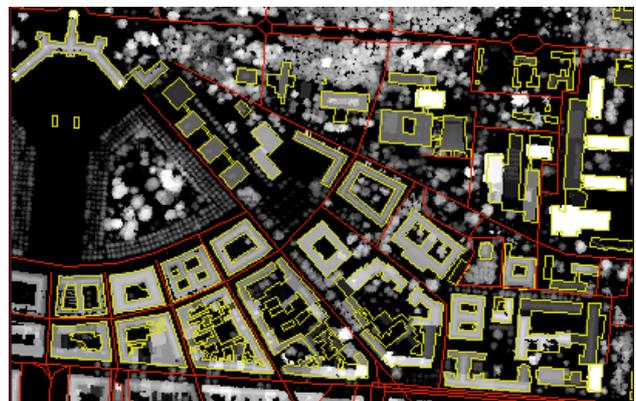


Figure 1. LIDAR DEM superimposed with vector map

2. SAR PHENOMENA IN URBAN SCENES

Fig. 2 illustrates typical effects in SAR images in the vicinity of buildings. The so-called layover phenomenon (Fig. 2a) occurs at locations with steep elevation gradient facing towards the sensor, like vertical building walls. Because objects located at different positions have the same distance to the sensor, like roofs, walls and the ground in front of buildings, the backscatter is integrated to the same range cell. Layover areas appear bright in the SAR image (Fig. 2c).

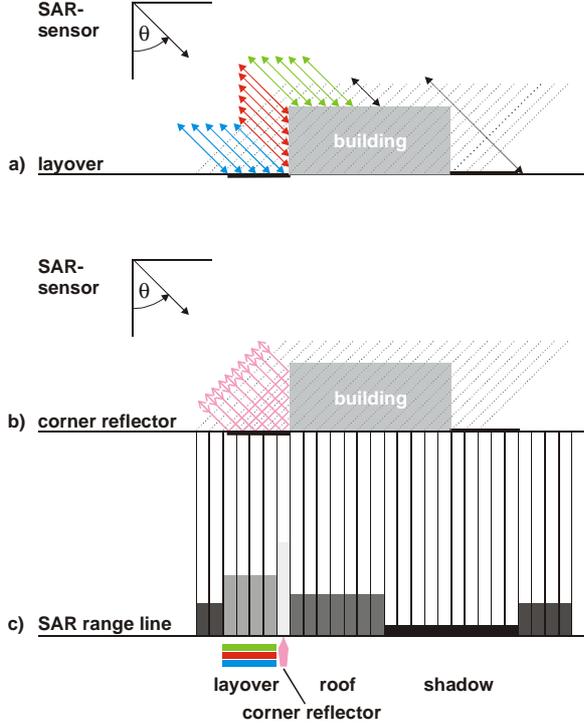


Figure 2. SAR Phenomena at a flat roofed building

Perpendicular alignment of buildings to the sensor leads to strong signal responses by double-bounce at the dihedral corner reflector between the ground and the building wall (Fig. 2b). This results in a line of bright scattering in azimuth direction at the building footprint (Fig. 2c). At the opposite building side the ground is partly occluded from the building. The region appears dark in the SAR image, because no signal returns into the related range bins. The mentioned effects are clearly visible in the SAR image of the test site shown in Fig. 3.



Figure 3. SAR image

In the following the phenomena of layover and shadow are discussed in more detail. The size of the layover areas l_g and shadow areas s_g on the ground in range direction depend on the viewing angle θ and the building height h . The layover area (see Fig. 4) is given by:

$$l_g = h \cdot \cot(\theta). \quad (1)$$

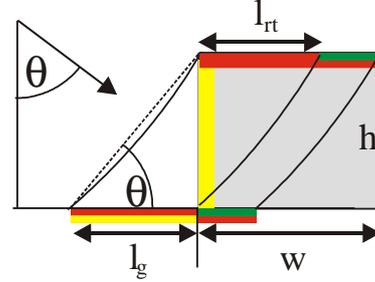


Figure 4. Layover in front and on a flat roofed building

In case of shadow similar relations are valid, as shown in Fig. 5. The slant range shadow length Δr is the hypotenuse of the rectangular triangle with the two sides h and s_g .

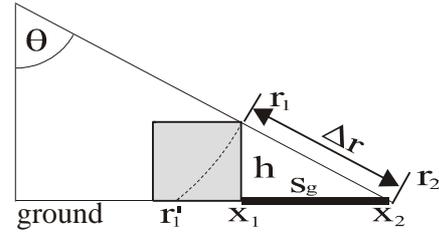


Figure 5. Shadow behind a building

Hence, the building elevation h can be directly obtained from

$$h = \Delta r \cdot \cos(\theta). \quad (2)$$

A simple projection of the slant range SAR data on a flat ground plane (ground range), ignoring the building elevation, leads to a wrong mapping of the roofs edge r_i to point r_i' . Starting from point r_2 the true position x_i of the building wall can be determined:

$$x_2 = r_2 \cdot \sin(\theta) \quad (3)$$

$$x_1 = x_2 - \Delta r \cdot \sin(\theta) \quad (4)$$

$$s_g = x_2 - x_1 = h \cdot \tan(\theta). \quad (5)$$

It is obvious, that at building locations a steep viewing angle leads to large layover areas on the ground and the roofs, but to small shadow areas and vice versa. Therefore, the viewing angle has to be chosen carefully.

The viewing angle increases in range direction over the swath. Assuming a viewing angle range between 40 and 60 degree, the shadow length of a certain building more than doubles from near to far range. In Figure 6 such a situation is depicted. In the worst case a road between two building rows is orientated parallel to the sensor trajectory. In this case the street is partly occluded from shadow and partly covered with layover. An

object on the road can only be sensed properly if a condition for the road width w_s holds:

$$w_s > s_{gn} + l_g = h \cdot (\tan(\theta_{sn}) + \cot(\theta_l)). \quad (6)$$

In the sketch in Figure 6 the angle θ varies remarkable between the two buildings. To consider the local properties at a road a constant θ is assumed. An angle of 55 degree in both cases and an building height of 15 m gives a minimum w_s of 31.9 m.

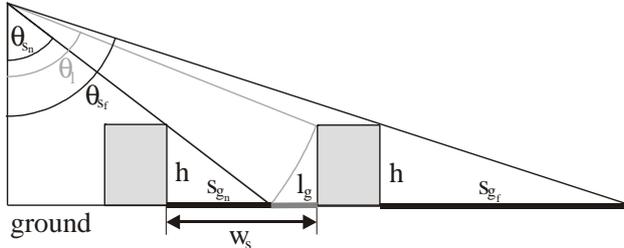


Figure 6. Shadow and Layover from buildings displaced in range direction

For the analysis of buildings the roof area which is influenced by layover l_r is of interest. At the far side of a building with width w a part of the roof is not interfered with layover (shown in green in Figure 4) if the inequation is fulfilled

$$h < w \cdot \tan(\theta). \quad (7)$$

3. SIMULATION OF SAR PHENOMENA

3.1 LIDAR data as ground truth

State of the art LIDAR systems achieve an elevation accuracy in the decimeter scale on a meter grid or better on the ground. The elevation is derived from a runtime measurement of infrared laser pulses emitted in nadir direction. A typical diameter of the footprint of the pulse on the ground is 30 cm from 300 m altitude (beam divergence 1 mrad). At trees the signal is usually partly scattered from the canopy and from the ground beneath.

The backscatter signal can be recorded in “first pulse” or “last pulse” mode (Fig. 7). Since the first pulse data represents the canopy better, this kind of data is suitable for the analysis of shorter radar wavelength signals which are mostly scattered from the canopy, e.g. X-band. In case of a longer radar wavelength, like L-band or P-band, last-pulse LIDAR data is the better choice.

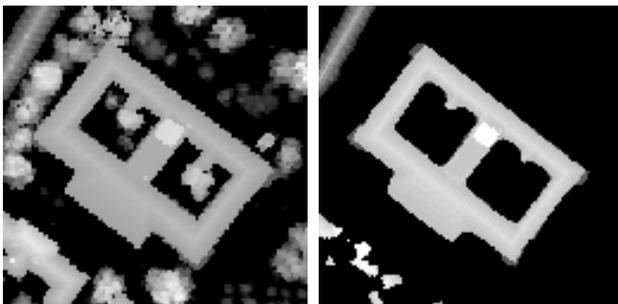


Figure 7. LIDAR data: first pulse (left), last pulse (right)

3.2 Simulation of Shadow and Layover

An approach proposed for satellite SAR data and DTM (Meier et al., 1993) was adopted for the simulation of layover and shadow areas from high resolution DEM. The part of the scene that can be sensed reliably from a given sensor position idea is determined. The analysis is restricted to the geometric alignment of the scene towards the sensor, neglecting antenna sidelopes and the aspect variation over the synthetic aperture. The elevation grid is sampled in range direction. For each bin the distance and viewing angle towards the sensor is calculated, which are analysed to detect shadow and layover areas.

The use of a coarse DTM restricts the approach to the terrain slope, which is often sufficient for satellite data. For an analysis of high resolution SAR data of urban scenes, elevated objects have to be considered as well. Even in dense urban areas trees may cover large portions of the terrain. Neglecting the influence of natural objects might result in too optimistic estimations of the visibility of man-made objects. The SAR test data was acquired in the X-band (HH polarization, ground resolution approx. 1m, $\theta = 55$ degree, sensor altitude 3000m). First pulse LIDAR data was chosen as ground truth to consider the canopy.



Figure 8. Layover (white), shadow (black), layover and shadow (dark grey) and reliable data (bright grey)

A result of the simulation of shadow and layover areas is illustrated in Fig. 8. Details are given in Table 1. The large viewing angle suggests a larger portion of shadow compared to layover. This would be the case if all objects in the scene were detached not interfering the signal of each other. But in the test scene the ground distance in range direction between the objects is often small. This results in many mixed pixels where shadow and layover are both present. Less than 20% of the road area can be sensed undisturbed. Especially for a building reconstruction from InSAR data the influence of layover on the elevation measurement has to be considered. Due to the signal mixture the elevation data tend to be too small at layover locations (neglecting the noise influence). Only 43% of the roof area is not interfered with layover or shadow.

	Complete scene	Roads	Building roofs
Shadow	28	38.5	16
Layover	25	18.5	33.5
Mixed	19	23.5	7.5
Reliable	28	19.5	43

Table 1 Result of shadow/layover simulation in per cent

3.3 Simulation of different aspects

In order to estimate the improvement by incorporating additional SAR measurements acquired from different aspects a large number of such problem area simulations were carried out. The aspect angle was altered in steps of 5 degrees. For each of the 72 aspect directions the layover and shadow areas were detected for 9 different viewing angles. The viewing angle θ was chosen between 30° and 70° with 5° increment. This results in 648 simulations. From this set the two, three and four best combinations were determined, maximising the portion of useful signal of the entire road respectively building area. The results for the best pair of aspects is shown in Table 2. In case of the roads the best result is achievable for an illumination from exactly north and west with a viewing angle of 45° . These directions coincide with the main road orientations. With a combined analysis are 47% of the road area sensed undisturbed, compared to 19.5% of the real SAR image alone. However, the partition of the road area which can be seen in both cases is small, because of the perpendicular illumination directions.

	Roads		Building roofs	
R_1, X_2	26	47	24.6	72.8
X_1, R_2	13		21.2	
R_1, R_2	8		27	
S_1, S_2	6.3	53	8.6	28.2
L_1, L_2	8.7		4.6	
Mixed	38		15	

Table 2. Combined results for sensing from directions (1,2) in per cent: shadow (S), layover (L), don't care (X), reliable (R)

The optimal four aspects with respect of the visibility of buildings are along the cardinal directions in the order east, north, west and south, with viewing angle 60 degree except for the north direction (70°). With the east, north combination more than 72% of the building roofs are undisturbed visible. Concluding from the large viewing angle of the advantageous measurements layover seems to be the critical phenomenon for a task like building reconstruction.

Table 3 shows the benefit from a third and fourth SAR measurement. In case of the roads the third illumination is along the tilted roads from 210° anti-clockwise towards north ($\theta = 50^\circ$) and the fourth from east to west with off nadir angle 60° .

	Roads	Building roofs
3 data sets	55.6%	81.5%
4 data sets	62%	86.5%

Table 3. Portion of reliable area combining 3 and 4 SAR images

4. DISCUSSION AND OUTLOOK

The analysis of buildings and roads in urban areas is limited due to the SAR sensor principle. With a single SAR measurement useful data can be acquired for a minor part of the object areas only. It was shown that taking additional SAR data from different aspects into account can overcome this limitation. Particularly, in case of the buildings the improvement is significant: more than 80% of the roofs are visible combining data of three carefully chosen aspects. This result encourages efforts to reconstruct buildings from SAR and InSAR data.

However, besides layover and shadow dominant scattering is present in the data. On the one hand these effects may be useful for the analysis like the strong response at the dihedral corner between building and ground. On the other hand objects in the neighbourhood of such dominant scatterers are often hardly visible. Fig. 8a shows a detail of the test data with strong signal at building locations. Locations of possible strong scattering (Fig. 8b) were detected by the analysis of 3D vector data derived from the LIDAR DEM (Soergel et al., 2002). This time consuming analysis was carried out for one aspect here. In future work the detection of strong scatterers will be considered in the determination of optimal SAR aspects.

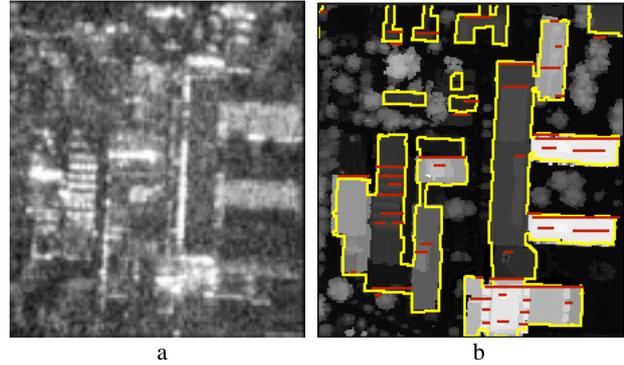


Figure 8. a) SAR image, b) DEM with building footprints (yellow) and possible corner structures (red)

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