ROAD EXTRACTION FROM HIGH RESOLUTION MULTI ASPECT SAR IMAGES

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ABSTRACT

In this paper, we propose a fusion strategy for extracted roads from multi-aspect SAR images. The fusion strategy extends a system for automatic road extraction from SAR images based on line extraction and explicitly modeled knowledge, which has been developed for single SAR images. Due to the side-looking geometry of SAR, the visibility of roads is often limited by adjacent high trees or building rows. Roads in viewing direction (range) are less affected by shadow and layover effects from neighbouring objects than roads across the viewing direction (azimuth). In the fusion step, road segments running in range direction, “good candidates for roads” are higher evaluated than roads in azimuth direction. The fusion technique was tested on a sub-urban SAR scene. The results show the potential of the proposed fusion strategy and the usage of multi-aspect SAR views in case of road extraction.

INTRODUCTION

Synthetic aperture radar (SAR) holds some advantages against optical image acquisition. SAR is an active system, which can operate independently on daylight and good weather conditions. Road extraction from SAR images therefore offers a suitable complement or alternative to road extraction from optical images. Automatic road extraction faces a new challenge, e.g. the recent development of new air- and space-borne high resolution SAR-systems [1], [2]. Still, automatic road extraction remains a difficult task, due to the side-looking geometry and speckle effects. Especially in urban or forest areas, roads are occluded by shadow and layover, caused by adjacent high buildings or other high vegetation. Furthermore, building structures, traffic signs and metallic objects in cities give rise to dominant scattering. The most prominent scatters are double-bounce scattering caused by reflections between the front of a house and the ground and triple-bounce scattering at trihedral corner structures at buildings. These imaging effects occlude important road information. In multi-aspect SAR images, the imaging effects occur differently. Therefore a road, which is occluded in one scene, may be visible in another image. Information extracted in multi-aspect SAR images suit as complements to each other.

Preliminary work [3] has shown that fusion of SAR images taken from perpendicular and anti-parallel views improves the extraction of urban road networks. The extraction in [3] is made in two steps, first a line detector adapted to the speckle statistics is used and afterwards a network based on a Markovian approach is reconstructed. The proposed method favours regular road network of mainly perpendicular crossroads.

The work presented in [4], has shown that a combination of multi-aspect SAR views improves the results of road extraction. The automatic road extraction procedure is performed using two fuzzy extractors. A fusion strategy is proposed in this work, which favours longer road segments.

Research has shown [5] that the illumination direction is important for the road visibility. For each of a set of aspect angles, simulations of layover- and shadow effects are carried out for a number of incidence angles. An urban area was chosen as a test scene. The results showed that the optimal visibility of roads was obtained, when the illumination direction coincide with the main road orientations.

In this paper, an approach for fusing extracted roads from multi-aspect SAR images, with special regard on SAR specific features is presented. Our approach is based on the automatic road extraction system developed at TUM [6] [7] for rural areas. In the first part we explain in detail the visibility aspects of roads in SAR images, with special focus on illumination problems (shadow) of objects beneath the road. Then, in the fusion part, each road segment is evaluated according to these rules for SAR images. While good candidates for road segments are kept, poor candidates for road segments are avoided. In the end, the results of road extraction from single and multiple views are discussed.

ROAD VISIBILITY ANALYSIS

Roads in SAR images appear as dark lines. The smooth surface of the road, behaves like a mirror, which totally reflects the signal. This leads to a low signal and homogeneous appearance of the road. In urban as well as rural areas, long stripe-like shadows occur frequently in SAR images. They results from shadow areas caused by the outer edge of a forest area or by a row of high trees or building. These are often the origin of false alarms and the problem is to differentiate between them and true roads. In forest areas, tree branches bending over the road give the road an irregular shape. The line extraction (see following chapter) applied in this work requires in most cases roads, which have at least one side clear from adjacent high objects. In the following part we will just consider roads surrounded by objects at one side.

The shadow effects are present at steep surfaces and depend on the incidence angle (off-nadir angle θ), the height of the target (h) and the slope of the target surface. The shadow of a tree row is depicted from the side (Figure 1a) and from above (Figure 1b). The shadow length perpendicular to the road (s_n) can be expressed as

$$s_n = s \cdot \sin(\beta) = h \cot(\theta) \sin(\beta), \tag{1}$$

where β is the angle between the range direction and the direction of the road. In this work, β is called the road visibility angle. For differentiation between road-like shadows parts and roads we introduce a maximum road visibility angle, β_{max};

$$w + a > s_n \rightarrow \sin(\beta_{max}) < \frac{w + a}{h \cot(\theta)}, \cos(\theta) = \frac{H}{D_{SR}}, \tag{2}$$

where H is the flight attitude and D_{SR} is the slant range distance. A road, which direction is within β_{max} is considered to be a road and not a shadow.

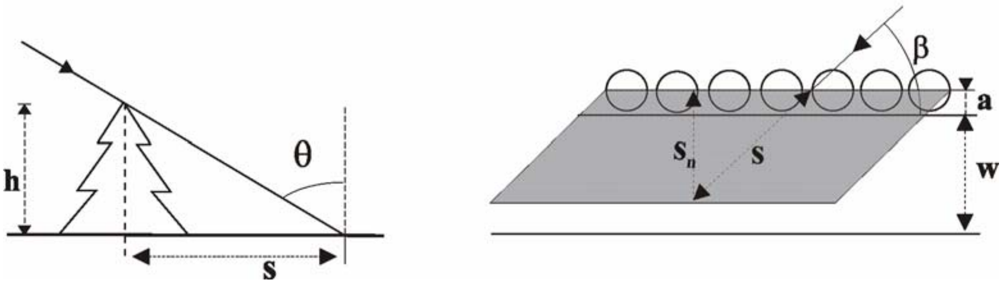

Figure 1. Shadow length of a row of trees a) Side view b) View from above

EXTRACTION AND FUSION OF ROADS FROM MULTI-ASPECT SAR IMAGES

The extraction of roads from SAR images is performed with the TUM road extraction approach [6], which was originally designed for optical images with a ground pixel size of about 2m [7]. The first step of the road extraction consists of line extraction using Steger's differential geometry approach [8]. Results from the line extraction step are shown in Figure 3a. By applying explicit knowledge about roads, the line segments are evaluated according to their width, length, curvature, constant width, etc (see Figure 3b). The evaluation is visualised in different colours on the principle of a traffic light. Green responds to "good road candidates", whereas red represents the worst candidates. A weighted graph of evaluated road segments is constructed. In this step, more global characteristics such as functionality and topology of the roads are considered. For the extraction of roads from the graph supplementary road segments are introduced and seed points are defined. In our case, best-valued road segments serve as seed points. They are connected by an optimal path search through the graph. The roads extracted in one single view are presented in Figure 3c-d.

The roads extracted in each single view are fused together by the following iterative fusion strategy. Each road is split into segments and each segment is evaluated with respect to its road visibility angle. All segments are sorted according to its weight. The best-evaluated segment is chosen first and is added to the final result without any modification. Then,

all neighbouring segments are searched for. Those parts of the neighbouring segments which satisfy overlap and collinearity criteria (i.e. buffer width and direction difference) are assumed to be redundant extractions and are removed. The best-evaluated segment is divided into not-fused and fused parts to give the overlapping parts different weights compared to the non-overlapping parts, thereby accommodating the support provided by the redundant segments. Non-overlapping segments keep their previous evaluation. Also, lines with an all too much deviant direction according to the best-evaluated line remain in its original state.
Then, the segment yielding the second highest evaluation is chosen and processed with the same algorithm. The whole fusion process ends after all segments have been processed. Finally, intersections are generated by checking for segments crossing each other. A fusion example is described in Figure 2.

a) b)

Figure 2. "Best-first" fusion a) Input: Line 1, 2, etc. are evaluated as best, second-best and third-best, respectively. b) Output: 1c is highest evaluated, while three lines are fused together; remaining parts of 2 and 3 keep their evaluation. Line 4 is not even considered due to its deviant direction with respect to line 1. The next step would be to fuse line 2 and 3. The buffer-width b is marked out in the figure.

Finally new roads based on the best-evaluated road segments (i.e. seed points) are generated. Only road segments that fulfil the following criteria are chosen as candidates for seed points;

- a road segment has to be detected at least twice

or

- the direction of a road segment is within β_{max} (see Equation 2).

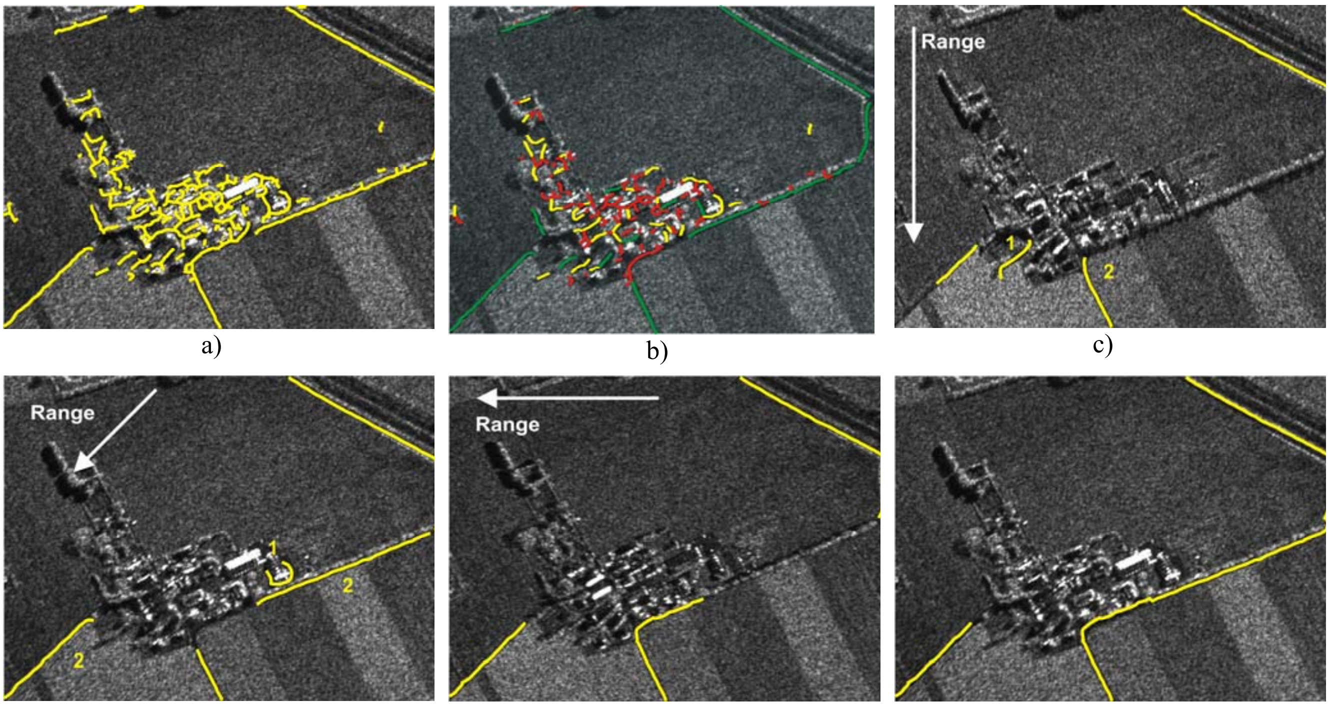

Figure 3. a) Line extraction results b) Evaluation of road segments c-e) Roads extracted in single SAR images viewed from the top, from the upper right corner and from the right. f) Results after fusion of extracted roads in Figure 3c-e.

RESULTS

The proposed fusion approach is tested on X-band, multilook SAR data with a resolution of about 0.75 m. The test area is located near the airport of DLR in Oberpfaffenhofen, southern Germany. The result of one test scene is presented in this article. The scene is illuminated from three aspect angles, 0°, 45° and 90°. The ground range SAR data was manually registered. The roads extracted in each single SAR view (Figure 3c-e) are fused and the resulting roads can be seen in Figure 3f. The candidates of the seed points are supposed to have a maximum deviating direction of ±30° with respect to the range direction. This value is chosen by a relatively wide margin (β_{max} ≈45°).

The resulting roads are more complete and more correct in comparison to the result of each single image. False alarm occurs (marked by 1), which disappears after the fusion. The road segments are neither high evaluated in the visibility analysis, nor occur in both scenes and do not connect any seed points. Some segments are highly evaluated (marked by 2) and both of them are present in the final results. Since the road network search is based on the shortest connection between seed points, each road network requires a seed point at the beginning of each road.

Especially interesting is the road marked by 2 in Figure 3d. This road represents our theoretical example in the beginning of the article. Trees are located at the upper side of the road. In one image (Figure 3c), the road is occluded by shadow and in the other image (Figure 3e), the road is occluded by layover. It is only visible in one of the images and due to its favourable direction the road is highly evaluated and remains in the final result.

The results after fusion shows, that not only more road segments are detected, also the number of “false alarms” is decreased. This assessment on object level is just a first step towards evaluation and can be performed in more sophisticated ways, based on a fuzzy-value, statistics, etc. In future improvements, we will introduce a more sophisticated assessment including quality evaluation, which will be performed in an earlier step of the road extraction process.

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REFERENCES

[1] A. Roth, “TerraSAR-X: “A new perspective for scientific use of high resolution spaceborne SAR data”, *2nd GRSS/ISPRS Joint workshop on remote sensing and data fusion on urban areas, URBAN 2003. IEEE*, pp. 4-7, 2003.

[2] H. Schimpf, H. Essen, S. Boehmsdorff, T. Brehm, “MEMPHIS – A Fully Polarimetric Experimental Radar”, *Geoscience and Remote Sensing Symposium*, *2002. IGARSS '02*, Vol. 3, pp. 1714- 1716, June 2002.

[3] F. Tupin, B. Houshmand and M. Datcu, “Road Detection in Dense Urban Areas Using SAR Imagery and the Usefulness of Multiple Views”, *IEEE Trans. on Geoscience and Remote Sensing,* vol. 40, pp. 2405-2414, November 2002.

[4] F. Dell’Acqua, P. Gamba and G. Lisini, “Improvements to Urban Area Characterization Using Multitemporal and Multiangle SAR Images”, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 41, pp. 1996-2004, September 2003.

[5] U. Stilla, E. Michaelsen, U. Soergel, S. Hinz, H.J. Ender, “Airborne Monitoring of vehicle activity in urban areas” In: Altan MO (ed) International Archives of Photogrammetry and Remote Sensing, 35(B3), pp. 973-979, July 2004.

[6] B. Wessel, C. Wiedemann, 2003. “Analysis of Automatic Road Extraction Results from Airborne SAR Imagery” Proc. ISPRS Conference "Photogrammetric Image Analysis" (PIA'03), International Archieves of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Munich 2003, vol. 34, pp. 105-110

[7] C. Wiedemann, S. Hinz, “Automatic extraction and evaluation of road networks from satellite imagery”, Int. Arch. of Photogramm. Remote Sens., Vol. 32, pp. 95-100, September 1999.

[8] C. Steger, “An unbiased detector of curvilinear structures”, *IEEE Trans. Pattern Anal. Machine Intell.*, Vol. 20, pp. 549-556, February 1998.