AUTOMATIC ROAD EXTRACTION BY FUSION OF MULTIPLE SAR VIEWS

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ABSTRACT:

In the last years a system for automatic road extraction from SAR images based on line extraction and explicitly modeled knowledge has been developed at the Technische Universitaet Muenchen (TUM). In this paper, this approach is extended towards the use of multiple views from different viewing directions. The visibility of roads in SAR images is often limited by neighboring tree or building rows on one or on both sides of the road. Only roads in viewing direction are less affected by shadow and layover effects from neighbored objects. Therefore, we introduce a fusion technique where each road segment is assessed according to its direction to the SAR sensor. Road segments running in along-track direction are higher evaluated in contrast to road segments running in across track. The proposed fusion technique is demonstrated on a sub-urban SAR scene. The scene is viewed by three different aspect angles. The result shows the potential of proposed fusion strategy: with the use of three views, the resulting road network is a more complete and more correct than for each single image.

1. INTRODUCTION

Road extraction is an important topic for the acquisition and updating of urban GIS. Due to the weather independency of synthetic aperture radar (SAR), road extraction from SAR images is a suitable complement or alternative to optical systems. This is central among others for traffic monitoring and disaster management. In case of traffic monitoring, periodically obtained images are desired and in case of disaster management, availability of information within some hours is needed. By the development of new, sophisticated SAR-system, automatic road extraction has reached a new dimension. Satellite SAR images up to 1 m resolution will be available in 2006 by the German satellite TerraSAR-X [Roth, 2003]. Airborne images already provide resolution up to 1 decimetre [Ender & Brenner, 2002]

However, automatic road extraction from SAR imagery remains still a complicated task. Due to the side-looking geometry, especially in urban areas, roads are occluded by shadow and layover, caused by adjacent high buildings or other high objects. Preliminary work has shown that fusion of multiple images each taken from perpendicular and anti-parallel views, improves the extraction of dense urban road networks [Tupin et al., 2002]. The extraction 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.

For road network extraction, simulations of SAR images of urban areas have shown that the usage of multi-aspect SAR images improves the results [Dell A'cqua et al., 2003]. They point out the problematic registration of the SAR data. SAR data of the same area taken with different viewing angles are completely different.

An approach of fusion of multi-aspect SAR images by applying a high resolution DEM [Soergel et al., 2004] was investigated. Geo-coding is carried out, by correlating dark image regions with simulated shadow areas predicted by a high resolution LIDAR DEM.

The illumination direction is of importance for the road visibility. A simulation of layover- and shadow effects of an urban area has shown, that the best results for the visibility of roads were obtained, when the illumination direction coincide with the main road orientations [Stilla et al., 2004].

In this article, we propose an approach for fusing road extraction results from multiple views, with special regard on SAR specific features. We apply a fusion of the single view results by evaluating the detected road segments according to their direction according to the SAR sensor. Hence, false road segments can be avoided. Our approach is based on the automatic road extraction system developed at TUM [Wessel et al., 2003] [Wiedemann et al., 1999] for rural areas. In single views this software often fails for more complex areas like urban or forest areas.

In this paper we use images recorded with different aspect angles for an improved extraction. In the first two parts of this article we explain in detail the visibility aspects of roads in SAR images, with special focus on illumination problems (layover and shadow) of objects beneath the road. Chapter 4 contains a presentation of the road extraction performance, which focuses on the fusion of different SAR views. In the end, the results of road extraction in single and multiple views are compared and discussed.

2. ROADS IN HIGH RESOLUTION SAR IMAGES

In contrast to optical images, 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.

2.1 Rural Areas

In rural areas, long lines, constant width and low curvatures signify the appearance of roads. Some parts of the roads might be occluded by adjacent objects, like high trees. But in general, roads are always connected to each other in a network.

2.2 Urban Areas

An urban scene is much more complex than rural scenes, which makes road extraction in cities much harder. In cities, building structures, traffic signs and metallic objects give rise to dominant scattering. The most prominent scatters are double-bounce scattering due to reflections between the front of a house and the ground and triple-bounce scattering at trihedral corner structures at buildings. Also side-lobes, due to specular reflections from house roofs or metallic structures, appear frequently in urban scenes and might thus hinder road information. Among the mentioned high scattering phenomena "normal" shadow- and layover effects might occlude a road totally.

3. VISIBILITY ANALYSIS

Due to the side-looking geometry of SAR, layover and shadow effects are significant for radar images for urban as well as for rural scenes. These 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. In Figure 1a, the length of a shadow s of a tree is depicted. The length of the layover l and the length of the shadow, s is given by,

$$l = h \cdot \cot(\theta), \quad (1)$$
$$s = h \cdot \tan(\theta). \quad (2)$$

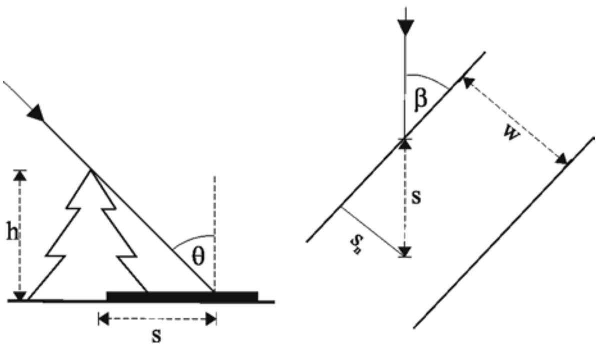


Figure 1. Shadow length of a tree. a) Side view: The shadow length s depends on the height, h, and the incident angle θ of the SAR sensor. b) View from above: The road visibility angle, β, is the angle between range direction and the road. s_n is the shadow length s projected on the normal of the road.

The layover and shadow effects raised by an object vary with the location of the object in relation to the position of the SAR sensor. Roads are preferably located in range direction to get the best possible visibility. The layover- and shadow lengths projected to the normal of the road (l_n, s_n) can be expressed as

$$l_n = h \tan(\theta) \sin(\beta), \quad (3)$$
$$s_n = h \cot(\theta) \sin(\beta), \quad (4)$$

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. This is depicted for the case of shadow in Figure 1b.

3.1 Objects Located at One Side

When trees are located at just one side of the road, either layover or shadow might occlude parts of the road. The smooth line structure is kept on the other side and line segments can in favourable cases be extracted. The main problem by layover effects is the decrease of the road width. Even though a linear structure remains, the width of the remaining road pixels may be below the width limitations for road extraction. Hence, roads affected by forest layover are restricted to a small limited number of road visibility angles. Dark shadow pixels however can be "included" into the road width and the extraction is possible, even in cases of large road visibility angles. Assuming a road of width 10 m bordered by 15 m high trees at one side, the road is detectable for road visibility angles smaller than 40° (θ≈45°). Within this angle the shadow occludes only a part of the road and can be viewed for the extraction as a part of the road itself. The maximum road visibility angle for which a line segment is still detectable is called β_{max}. Table 1 displays the variations of β_{max} for near, middle and far range.

	Width w (m)	Height h (m)	β_{max} near range θ=20°	β_{max} middle range θ=40°	β_{max} far range θ=60°
Secondary Roads	10	15	<90°	53°	23°
Main Roads	15	15	<90°	<90°	35°

Table 1. Maximum road visibility angle β_{max} for which still almost one road pixel is visible for main and secondary roads in near, middle and far range, θ is the incidence angle.

3.2 Objects Located at Both Sides

When a road is surrounded by high objects at both sides, the situation is more difficult. Even roads situated exactly in range direction are hard to extract. In forest areas, tree branches bending over the road give the road an irregular shape and a line is almost possible to extract. Simulated layover and shadow effects of a footpath in a park illuminated from two different aspect angles (β≈0° and β≈10°) are shown in Figure 2a-b [Soergel et al., 2003]. The location of the road is visible in red. Within a 10° of variation hardly any road pixels in Figure 2b of the road are visible. The same situation can be viewed in real SAR images (Fig. 3a-b). Even though the road is orientated almost in range direction (Fig. 3a), still some of the road pixels are missing. A line structure is hardly recognizable. But the situation is much worse, when the road is located in azimuth range and just a narrow shadow line can be detected (Fig. 3b).

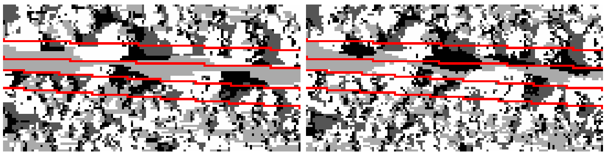


Figure 2. Simulated shadow- and layover effects: Black = shadow, dark grey= shadow and layover, light grey = road, white = layover, incidence angle θ= 45° a) β≈ 0°, b) β≈ 10°

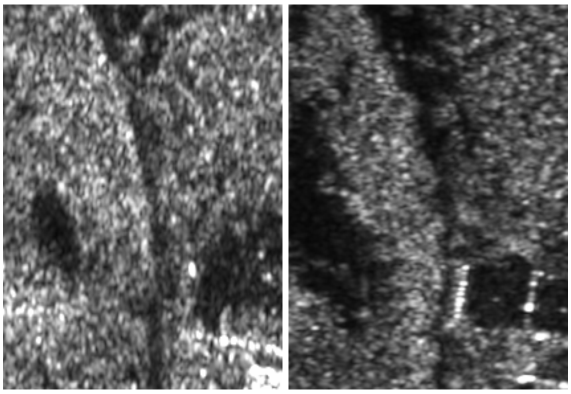


Figure 3. E-SAR image (X-band) of a road in a forest area, which is illuminated a) from the top and b) from the right

4. FUSION OF MULTIPLE SAR VIEWS

In this chapter, the automatic road extraction for multiple SAR views will be described. First the road extraction approach will be described briefly. Afterwards the focus will be on the fusion algorithm and its application for multiple SAR views.

4.1 Road Extraction

The extraction of roads from SAR images is performed with the TUM road extraction approach [Wessel et al., 2003], which was originally designed for optical images with a ground pixel size of about 2m [Wiedemann et al., 1999]. The first step of the road extraction consists of line extraction using Steger's differential geometry approach [Steger, 1998] By applying explicit knowledge about roads, the line segments are evaluated according to their width, length, curvature, etc. Lines from different image channels can be fused using a "best first" strategy described in section 4.2. Then a weighted graph of evaluated road segments is constructed. For the extraction of the road network 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.

4.2 Fusion of Road Segments

In this section, the fusion algorithm used for the multi-aspect image fusion will be explained. All overlapping lines are fused within a certain buffer-width ("best-first" strategy). The best-evaluated line is chosen as correct line. The second-best line is shortened and follows at the end of the correct line. The lines are not geometrically corrected and therefore many gaps remain between the lines. The fusion steps are depicted in Figure 4. Assume that line 1 and 2 are highest and second highest evaluated. All lines are within the buffer-width. After the fusion step, line 1 remains in its original state, line 2 is shortened and line 3 is deleted. Fused lines obtain higher evaluation, because the evidence for a road increases. The shortened lines keep their previous evaluation. Afterwards new intersections are generated.

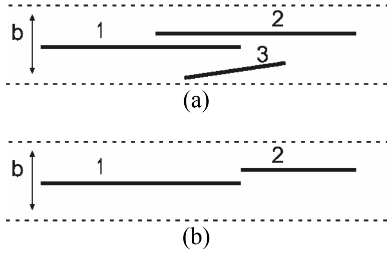


Figure 4. "Best-first" fusion strategy a) Input: Line 1, 2 and 3 are evaluated as best, second-best and third-best, respectively. b) Output: 1 is kept, 2 is shortened and 3 is deleted. The buffer-width *b* is marked out in the figure.

4.3 Strategy for Fusion of Multiple SAR Views

Generally, the fusion of multi-aspect images can be done at the beginning, in the middle or at the end of the road extraction process. In our case, all multiple views deliver already good candidates for roads. Therefore, we fuse the extracted road networks at the end of the extraction process. A first selection in each single road extraction has already been performed. All remaining road segments fulfill prerequisite criteria as constant width, length and low curvature, etc. The aim of the fusion of multiple views is on one side to improve the evidence by an at least twice extracted road from different views and on the other side to select the most suited image in the case of occlusions. Therefore, the following step is supposed to select the best candidate seen from a geometrical point of view and to differentiate between shadow and road segments. As we showed before, regarding the geometry, roads are best visible in range direction.

The extracted roads of each image are splitted back into road segments and each road is evaluated due to its direction according to the SAR sensor, according to Table 1. The result is finally fused together. In the end a new road network based on the best-evaluated road segments (i.e. seed points) is generated. Candidates for seed points have to fulfil the following criteria

- a line has to be detected at least twice

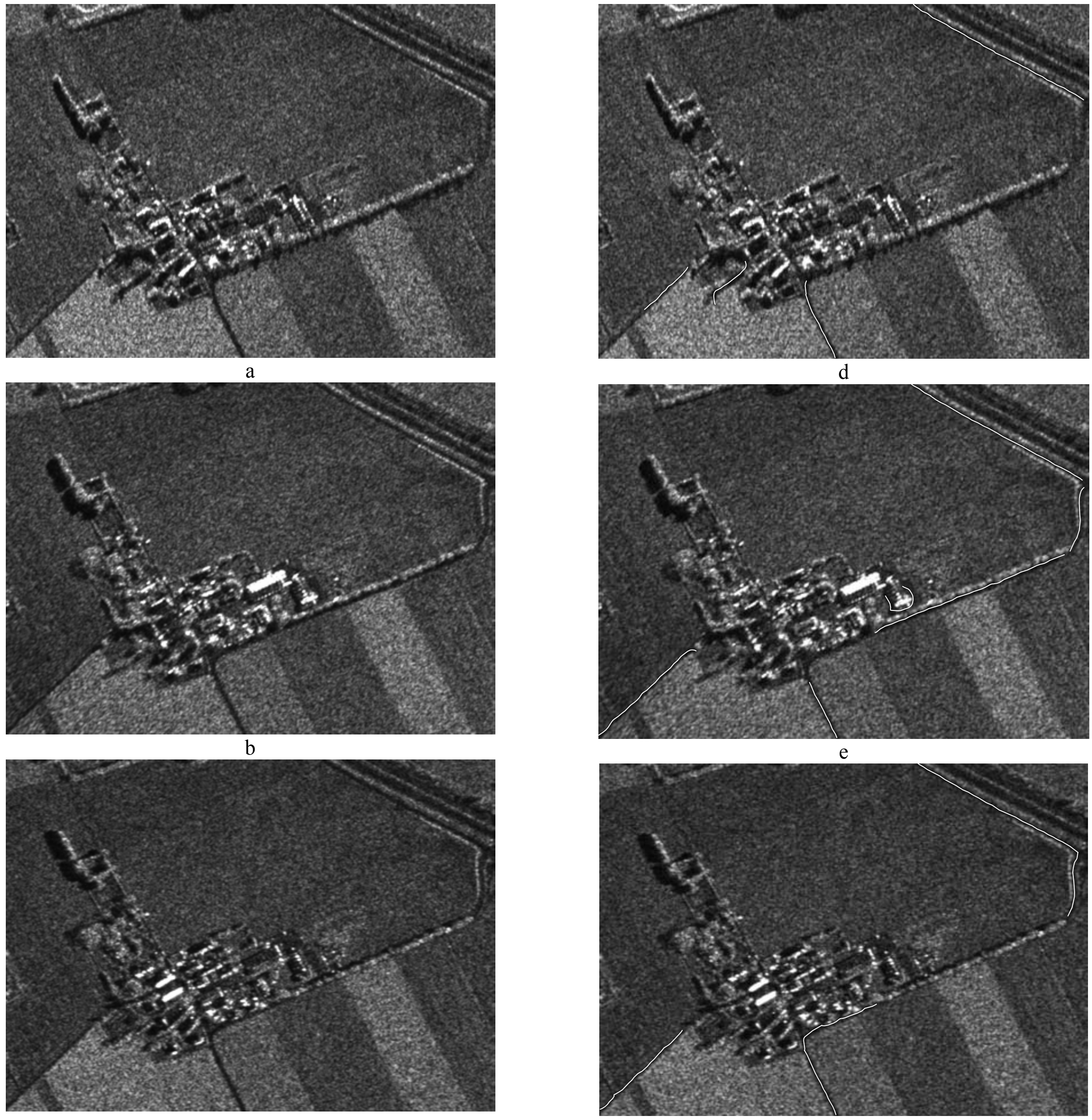
or

- the direction of the line is within β_{max} (see sect. 3.1 and Table 1)

All roads within β_{max} are assessed to α_1 and the rest to α_2. As seed point value, ρ can be chosen,

$$\begin{aligned} &\alpha_1 > \rho, \\ &\alpha_2 < \rho < 2\alpha_2, \end{aligned} \qquad (5)$$

To be a part of the final result, each extracted road has to be of a certain minimum length.



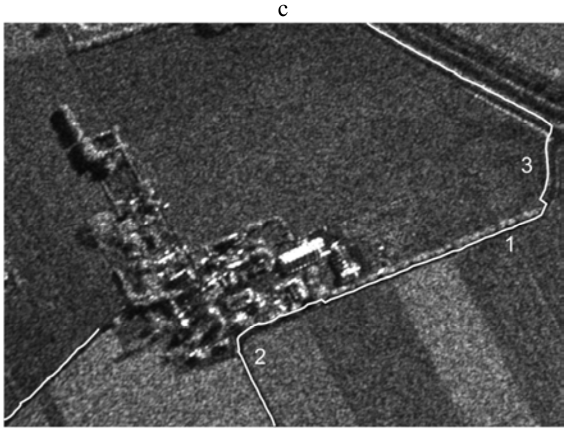


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Figure 5. The SAR scene is viewed a) from the top, the aspect angle is 0° b) from the upper right corner, the aspect angle is 45° c) from right to left, and the aspect angle is 90°. d-f) The extracted road segments in each single view are marked white. g) The fused results of the single view road networks in d-f.

5. RESULTS

The proposed fusion approach is tested on X-band, multi-look, ground range SAR data with a resolution of about 0.75 m. The small test area viewed in Figure 5a-g is located near the airport of DLR in Oberpfaffenhofen, southern Germany.

The scene is taken from three different aspect angles 0°, 45° and 90°, once from the top of the image (Fig. 5a), once from the upper right corner (Fig. 5b) and once from the right (Fig 5c). Each single extracted road network is depicted in Figure 5d-f.

An example for the use of fusing different directions can be found by the upwards-diagonal road in the middle (marked (1) in Fig. 5g). Trees are located at the upper side of the road. For an illumination from the top, the road is almost perpendicular to range direction (Fig. 5a). The road is totally covered by shadow and has an irregular shape. The extracted line is already in the single analysis ruled out, due to its irregular shape (Fig 5d). When the aspect angle is 45°, the road is also partly occluded by shadow (Fig. 5b). Still the line structure of the road is kept and the road is extracted (Fig. 5e). Due to its favourable location (i.e. the road visibility angle is relatively small), the road is evaluated highly to α_1. In the third image (Fig 5c), the illumination comes from the right side and the road is occluded by layover. Hence, no extraction occurs (Fig. 5f). Even though the road can only be extracted from one view, the road was highly assessed and therefore remains in the final network (Fig. 5g).

The same phenomenon can be observed by the vertical road (2) (Fig. 5g). The road is situated in range direction in the first view (Fig. 5a) and is highly assessed. After the curve, the road is bordered by buildings. It is now perpendicular to range direction and no longer detectable (Fig. 5d). Instead this horizontal road segment is highly evaluated for an aspect angle of 90° (Fig. 5c) and for that reason a part of the final result (Fig. 5f).

If a road is detected in two images, it shall be kept in the network, which is also the case for the vertical road (3) in the upper right part. Due to its low contrast, it is not detected in Figure 5a. Instead the road is clearly visible in both Figures 5b-c. The road is in none of the images highly evaluated, but is detected twice and obtains the final value of $2\alpha_2$.

False alarms occur in two of the images (Fig. 5d-e) which are badly evaluated in both single images and are therefore suppressed in the final road network (Fig. 5g).

Further, some explanations to the missing road parts: Since the road width is limited to 10 m, the highway in the upper right corner is not detected. Instead, a secondary road along the highway is extracted. Besides, hardly any roads within the small village are detected. As mentioned earlier, the road extraction approach was designed for rural areas and therefore requires lines, which are hardly ever present in urban SAR images.

6. CONCLUSION

In this paper we proposed a method for fusing road extraction results for multiple views. We managed a fusion strategy, which is based on selecting the best direction according to a visibility analysis.

Regarding just road extraction by using multiple views, the conclusion can be made that not only the completeness (i.e. more road segments are extracted) of the road network is improved; also the correctness (i.e. less false alarms occur) reaches a higher value by fusion of multiple SAR views.

In any case, this analysis showed the capability of the "quality-ensuring" of the objects from a geometrical point of view. 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 the assessment already in the single analysis and to carry out the fusion at segment level instead of final single road networks. This would probably give a better result especially in case of larger and more complex scenes.

7. ACKNOWLEDGEMENTS

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REFERENCES

Ender, J.H.G., Brenner, AR., 2002. PAMIR – a wideband phased array SAR/MTI system. IEE Proceedings-Radar, Sonar, Navigation, 150(3): pp. 165-172.

Dell'Acqua, F., Gamba, P., Iodice, A., Lisini, G., Riccio, D., Ruello, G., 2003. Simulation and Analysis of Fine Resolution SAR Images in Urban Areas, 2nd GRSS/ISPRS Joint Workshop on "Data Fusion and Remote Sensing over Urban Areas", URBAN 2003. pp. 133-136.

Roth, A., 2003. 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.

Soergel, U., Thoennessen, U., Stilla, U., 2003. Visibility analysis of man-made objects in SAR images. 2nd GRSS/ISPRS Joint workshop on remote sensing and data fusion on urban areas, URBAN 2003. IEEE, pp. 120-124

Soergel, U., Cadario, E., Thoennessen, U., 2004. Geocoding and fusion of airborne high-resolution multi-aspect SAR data. Proc. of EUSAR, pp. 945-948.

Steger, C., 1998 An unbiased detector of curvilinear structures, IEEE Trans. Pattern Anal. Machine Intell., 20(2), pp. 549-556

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

Tupin, F., Houshmand, B., Datcu, M., 2002. Road Detection in Dense Urban Areas Using SAR Imagery and the Usefulness of Multiple Views, IEEE Transactions on Geoscience and Remote Sensing, 40(11), pp. 2405-2414

Wessel, B., Wiedemann, C., 2003. Analysis of Automatic Road Extraction Results from Airborne SAR Imagery. In: Proceedings of the ISPRS Conference "Photogrammetric Image Analysis" (PIA'03), International Archieves of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Munich 2003, 34(3/W8), pp. 105-110

Wiedemann, C., Hinz, S., 1999. Automatic extraction and evaluation of road networks from satellite imagery, International Archives of Photogrammetry and Remote Sensing, 32(3-2W5), pp. 95-100

Wiedemann, C., 2001. Extraktion von Straßennetzen aus optischen Satellitenbilddaten, Dissertation