ANALYSIS OF AUTOMATIC ROAD EXTRACTION RESULTS FROM AIRBORNE SAR IMAGERY

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ABSTRACT:

Automatic extraction of roads is a present research topic. Many applications like topographic mapping, navigation applications, or image registration could profit from such algorithms.
This paper is concerned with automatic road extraction from synthetic aperture radar (SAR) imagery. An approach originally developed for the extraction of roads in rural areas from optical imagery with a ground pixel size of about 2 m is evaluated based on the comparison of the extraction results with reference data. Three large test sites were used, for which high-resolution SAR data (0.5 – 2 m), topographic map data, as well as manually plotted reference data are available. Both, the map data and the manually plotted reference data, are separated into three classes: highways, main roads, and secondary roads. The comparison shows that the extraction results strongly depend on the road classes: For main roads quite satisfying results can be achieved. Also, for highways the results are acceptable, with the restriction that no strong scattering objects, like traffic signs or bridges, interfere the road. The results for secondary roads from the 2 m E-SAR imagery are rather incomplete, due to the low visibility. In case of the high-resolution AeS-1 SAR imagery interfering objects of the industrial scenery lead to an incomplete extraction of secondary roads.

1. INTRODUCTION

Automatic road extraction has been a research topic since several years, from optical images as well as from SAR images. An early approach for detection of roads in low-resolution aerial imagery comes from (Fischler et al., 1981). In a first step, two kinds of detectors based on local criteria are used and the responses are combined. Then, in a more globally step, the road network is extracted by either a graph search or dynamic programming. This approach was also applied to SAR images by e.g. (Samadani and Vesecky, 1990). For high-resolution imagery (McKeown and Denlinger, 1988) set up a road model for their road tracking algorithm. (Bazohar and Cooper, 1996) used this approach for an automatic road extraction by defining Markov random fields (MRF). From this, roads were detected by a local maximum a posteriori probability (MAP) estimation.

Automatic extraction of linear features from SAR images especially taking into account the statistical properties of speckled SAR images is done by e.g. (Hellwich, 1996), (Tupin et al., 1998), and (Kartartzis et al., 2001). (Tupin et al., 1998) perform a local detection of linear structures based on two SAR specialized line detectors. The results are fused and the candidates for road segments are organized as a graph. The completion of the network is realized by a MRF. With a priori knowledge about roads available by the MRF a maximum a posteriori probability (MAP) criterion is identifying the best graph. (Kartartzis et al., 2001) improve the approach from (Tupin et al., 1998) and integrated the morphology method of (Chanussot and Lampert, 1998) for selecting road regions for an automatic extraction of roads from airborne SAR images. (Jeon et al., 2002) apply road detection to space borne SAR images. Roads were detected as curvilinear structures and grouped to segments using a generic algorithm (GA), which is a global optimization method. The GA uses perceptual grouping factors, such as proximity, cocurvilinearity, and intensity. Finally, the road network is completed by using snakes.

In this paper an approach for automatic extraction of roads developed at Technische Universität München (TUM) is evaluated (Wiedemann and Hinz, 1999). The TUM approach is based on the extraction of lines from different image channels. By introducing explicit knowledge about roads, hypotheses for road segments are generated. Then, the road segments extracted from different image channels are fused, road junctions are introduced, and a weighted graph of road segments is constructed. In order to close gaps between road segments, weighted links are added to the graph. Finally, a road network is extracted connecting seed points by optimal paths through the weighted graph.

In this paper we want to investigate the potential of the TUM approach for automatic extraction of roads from airborne SAR imagery. The approach was developed for optical imagery, so we present in the first part the algorithm itself and some modifications towards SAR imagery. We carry out extensive experiments on three larger test sites of about 120 km^2 in total from high-resolution SAR imagery and evaluate the achieved results by comparing the road extraction results to reference data regarding different road classes. Additionally, we distinguish between the content of a topographic map and what a skilled operator is able to detect in the data.

2. ROAD EXTRACTION

The used approach for automatic road extraction consists of several steps, which are shown in Figure 1. In the following a short description of each step is given and the adaptations made for SAR and for large data sets are outlined. A more

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detailed description of the approach is given in (Wiedemann and Hinz,1999) and (Wiedemann and Ebner, 2000).

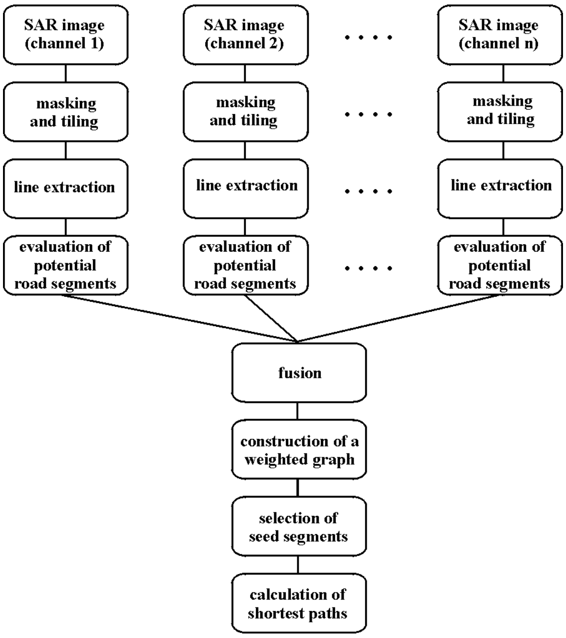


Figure 1. Road extraction workflow

Pre-processing: Some preparing steps are necessary to handle the data. In particular, test site 1 and 2 consist of 3 tracks, which have to be radiometrically adjusted to use the same parameter set for the whole test site. To assure a constant radiometry we correct the near far range illumination loss for each track. In order to keep low speckle, we use the multi-look, geocoded X- and L-band data.

In the test scenery exist many residential areas and forests. In these areas, the proposed road model does not fit and many false alarms are to be expected. Since the computation time increases with the number of potential road segments we exclude the regions of no interest from the extraction. A mask containing cities and forests is generated by X- and fully polarimetric L-band data based on the intensity values, ratios, and neighbourhoods using the eCognition software of Definiens (User Guide eCognition, 2003). Both masks, a threshold and the city/forest mask, are united and introduced into the line extraction.

For subsequent line extraction the imagery was tiled to control the computational effort.

Line extraction: Line extraction can be performed in multiple images of different radiometric and/or geometric resolutions separately using the differential geometry approach described in (Steger, 1998). A few, semantically meaningful parameters have to be chosen: The maximum width of the lines to be extracted and two threshold values according to the local radiometric contrast between lines and their surroundings. The result of the line extraction is a set of pixel and junction points for each image in sub-pixel precision. The extraction is not complete and contains false alarms, i.e., some roads are not extracted and some extracted lines are not roads.

Evaluation of potential road segments: In the next step, the lines are evaluated, according to their fitting to a regional model of roads. This incorporates the assumption that roads mostly are composed of long and straight segments having constant width and reflectance. Linear fuzzy functions are used to transform these properties into specific fuzzy values. An overall fuzzy value for each line is derived by aggregation of the specific fuzzy values.

Fusion of different image channels: The potential road segments of all channels are fused.

Construction of a weighted graph: After evaluating the road segments, more global characteristics of roads are considered in terms of the functionality and topology of roads. A weighted graph is constructed from the potential road segments of all channels. Costs for each potential road segment are calculated by dividing the length of the road segment by its overall fuzzy value. These costs are assigned to the respective edges of the graph. The weighted graph contains gaps because, in general, not all roads were detected by the line extraction. Therefore, each gap is evaluated based on the collinearity, absolute and relative gap length (compared to the adjacent lines).

Selection of seed segments: For the network generation various seed points have to be selected. The segments with relatively high weights are selected. Therefore, the extraction depends strongly on the parameters from the fuzzy values of the evaluation of the road segments.

Calculation of shortest path: Each pair of seed points is connected by calculating the optimal path through the graph using the Dijkstra algorithm. The main disadvantage of that procedure is that if there are two gaps longer than the maximum gap length, e.g. caused by low contrast, it may be that the part between these gaps cannot be added to the road network, because no connection with the seed points can be established through the graph.

Some adaptations of the TUM road extraction strategy towards SAR imagery were made. The advantage of roads in SAR imagery is that they appear mostly as dark lines. Their surface is relatively smooth compared to the radar wavelength. Therefore, they reflect in a specular way - away from the slope illuminating SAR sensor. On account of this, it is possible to facilitate the extraction by using directly the intensity of each pixel, in addition to local contrast information. We established this in two ways: first by a threshold before the line extraction. The threshold is used to restrict the extraction to the relevant (dark) areas. Second by introducing the absolute grey value as criteria for the evaluation of potential road segments. This has the advantage that the parameter settings for the line extraction can be softened and fewer false alarms are extracted.

3. EVALUATION

The evaluation of the automatically obtained results is done by a comparison to reference data (Wiedemann et al., 1998). Here, vector data of a topographic map and manually plotted road axes are used as reference data. A brief description of the evaluation procedure is given below.

The comparison is carried out by matching the extracted data to the reference data using the so-called “buffer method”, in which every proportion of the network within a given distance (buffer width) from the other is considered as matched. Two questions are thought to be answered by means to the defined quality measures: (1) How complete is the extracted road network, and (2) How correct is the extracted road network. The completeness indicates the percentage of the actually present road network, which could be extracted, whereas the correctness is related to the probability of an extracted linear piece to be indeed a road.

Completeness is defined as the percentage of the reference data, which lies within the buffer around the extracted data:

$$completeness = \frac{length\ of\ matched\ reference}{length\ of\ reference} \quad (1)$$

Correctness represents the percentage of the correctly extracted road data, i.e., the percentage of the extracted data lying within the buffer around the reference network:

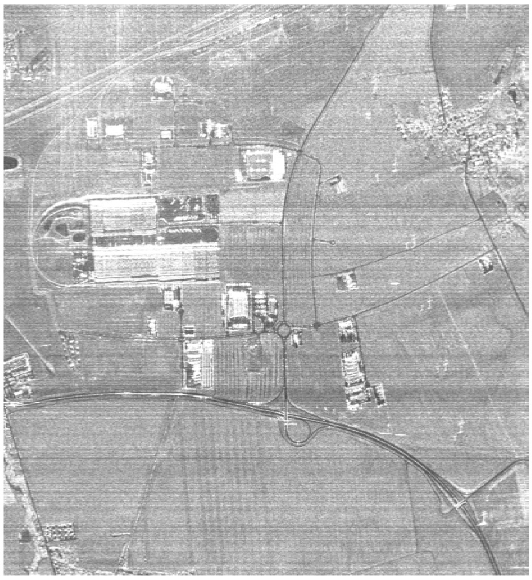
$$correctness = \frac{length\ of\ matched\ extraction}{length\ of\ extraction} \quad (2)$$

In addition, also the geometric accuracy of the correct extraction is assessed and expressed as RMS difference.

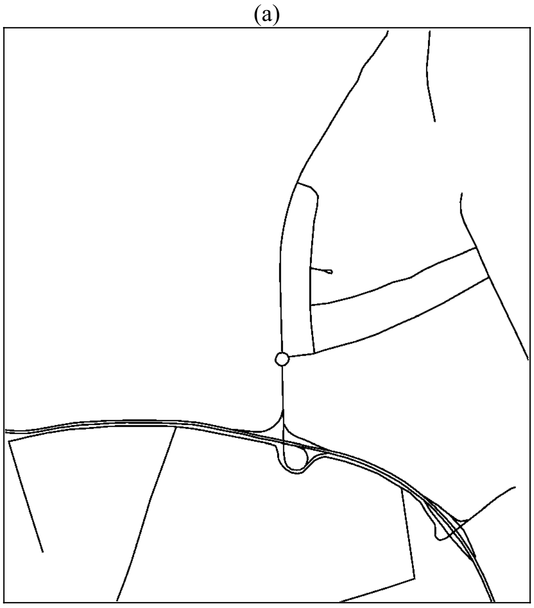
4. RESULTS AND DISCUSSION

In this chapter we present the results of the described road extraction approach, applied to three test sites of an area of approximately 120 km^2 in total. The images were taken with two SAR sensors with different resolution.

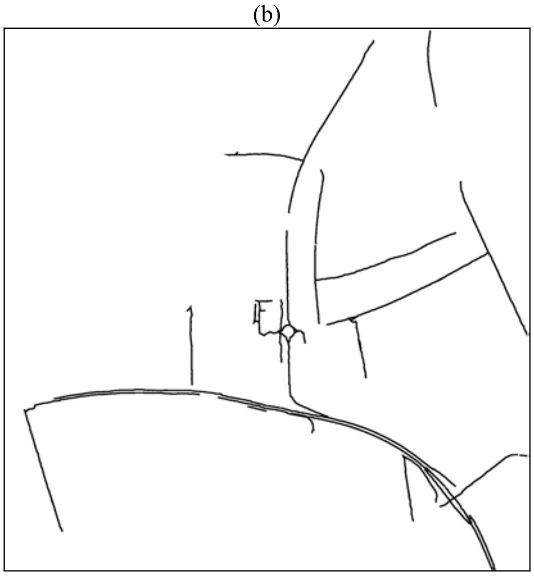
1) Test site 1: Ehingen, Southern Germany, taken by the E-SAR sensor from the German Aerospace Center (DLR) (Horn et al., 2000), covers an area of about 7.5 km × 11 km and is composed of three tracks. For the test geocoded multi-look X-Band and L-Band data taken within the ProSmart II project (ProSmart II, 2003) in 2001 are used. The ground resolution is about 2 m, respectively 3 m with a pixel spacing of 1 m. It is a rather rural scenery.
2) Test site 2: Erfurt, Eastern Germany, taken by the E-SAR sensor, represents land coverage of about 40 km^2 and is composed of three tracks. The test data set comes from the Prosmart II project as well and has the same resolution. The industrial, rural scenery contains apart of main and secondary roads also highways.
3) Test site 3: Munich, Southern Germany, taken by the AeS-1 sensor from Aerosensing in 1999 (Schwäbisch and Moreira, 2001). The area is about 12 km^2 and composed of two tracks. The original resolution is 0.5 m for multi look X-Band image with horizontal polarization (X-HH). The resolution is resampled to 1 m for the test. The industrial test site is located near the Munich new trade fair center.



(a)



(b)



(c)

Figure 2. Part of test site 2 (a) Erfurt X-HH image, (b) Roads of the manual reference, (c) Extracted roads

Figure 2(a) shows a part of the used geocoded, multi-look SAR image of test site 2. The scenery contains highways, main roads, and different types of secondary roads. Highways consist of four or more lanes separated by a crash barrier. Main roads comprise two wide lanes. Secondary roads are two-lane roads. The distinction between different types of secondary roads in the topographic map reference is more formal, so they are grouped to one class of secondary roads.

For the evaluation of the road extraction results we take into account on the one hand all roads which are really existent in the scenery and on the other hand only those roads which are visible in the SAR imagery, i.e., two classes of reference data are used: a digital topographic map and a reference extracted manually from the SAR imagery. The vector data of the topographic map were obtained from aerial photography in scale of 1:10,000. The geometric accuracy is nominal 3 m. The manually extracted reference was plotted by an operator. The classification of the roads to major and minor ones was decided in case of doubt by comparison to the topographic map reference. Since the used automatic road extraction approach works only well in open areas, city streets and forest roads are excluded from both references as in the extraction. We carry out the following tests:

Test 1: using X-HH data; extraction of wide lines.
Test 2: using X-HH data; extraction of wide and narrow lines.
Test 3: using X-HH, X-VV, and L-VV data; extraction of wide lines.

In co-polarized channels roads are more clearer visible, due to the lower influence of volume scattering of surrounding vegetation than in cross-polarized channels (Lee et al., 2001). Therefore, for the third test the L-VV channel is chosen from all polarizations of the L-Band. For test site 3 no L-Band data are available.

The parameter settings are optimized on smaller subsets for test site 1 and 3. Test site 2 was processed using the same set of parameters as for test site 1, to test the transferability of the parameters. The results are evaluated using the topographic map reference data as well as the manually plotted reference data. The evaluation is carried out for each category of roads separately. The resulting quality measures are summarized in Table 2- 4 and discussed in the following sections.

4.1 Comparison of reference data

Regarding the two references, the highways and main roads of the manually plotted references correspond mostly with the topographic map reference in all test sites. In contrast, secondary roads could not totally be gathered during the manual extraction of the reference data, e.g., in test site 1 about 25 % of the secondary roads are missing in the manual reference. In the high-resolution test site 3 the secondary roads are mapped relatively complete, despite of parking lots. The vast majority of the topographic map reference is correct, but in test site 3 some positioning errors of parts of the highway exist. Therefore, the RMS error for this test exceeds the normal average value of 2 m.

4.2 Comparison of the three tests

First analyzing the overall results of the test sites it is important to note that the extraction with two different line widths yields by far the best results regarding the completeness and the correctness. Here, especially main and secondary roads are relatively complete, which is a consequence of the additional extraction of narrow lines in *test 2* in comparison to *test 1*. The L-Band used in *test 3* does not improve the road extraction results. Though, the completeness of highways and main roads is better than in the other tests, the completeness of secondary roads is reduced by fusing the lower resolution L-Band lines.

4.3 Comparison of the road classes

The proportion of found main roads is relatively high, contrary to highways. Though highways in the test sites 2 and 3 are clearly visible, the result of the automatic road extraction is incomplete for this road category, see Figure 2(c) and Figure 3. This is because especially traffic signs, bridges, and other strong scattering metal objects impede the extraction. To improve the results, disturbing objects have to be explicitly modelled and lines could be grouped to parallel lanes, which is not the case in the current implementation. If the strong scattering objects could be extracted reliably, a solution would be the integration of these objects to use them as evidence for roads.

Test site 1 (Ehingen)						
	Manual reference			**Topographic map reference**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Band	X-HH	X-HH/X-HH	X-HH/X-VV/L-VV	X-HH	X-HH/X-HH	X-HH/X-VV/L-VV
Line width	13m	8m/13m	13m/13m/13m	13m	8m/13m	13m/13m/13m
Completeness	**70.6 %**	**75.3 %**	**65.5 %**	**59.4 %**	**64.1 %**	**55.1 %**
main roads	80.4 %	87.6 %	88.9 %	77.9 %	85.3 %	86.7 %
secondary roads	67.2 %	71.1 %	57.4 %	54.4 %	58.1 %	46.2 %
Correctness	**74.6 %**	**71.0 %**	**60.0 %**	**75.1 %**	**72.1 %**	**60.3 %**
RMS	**2.1 m**	**2.0 m**	**2.1 m**	**2.9 m**	**2.8 m**	**2.9 m**
Correctness incl. ways				**87.3 %**	**89.4 %**	**80.7 %**

Table 2. Evaluation of road extraction results of test site 1; compared to manual reference data and to topographic map data

Test site 2 (Erfurt)			
	Manual reference		
	Test 1	**Test 2**	**Test 3**
Completeness	**43.0 %**	**46.7 %**	**41.3 %**
highways	42.7 %	46.8 %	46.5 %
main roads	90.5 %	78.6 %	91.9 %
secondary roads	30.9 %	38.7 %	25.6 %
Correctness	**55.5 %**	**72.0 %**	**50.5 %**
RMS	**1.9 m**	**1.8 m**	**1.9 m**

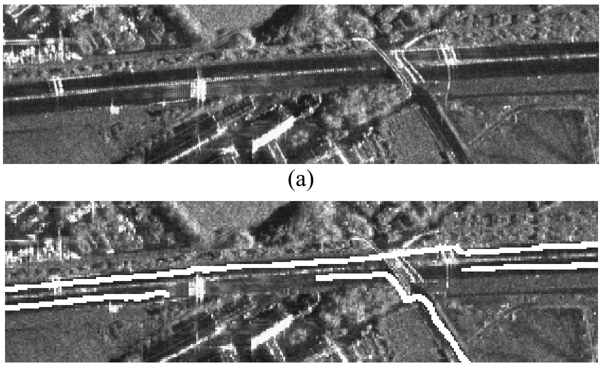
Table 3. Comparison of extraction results to manual extraction of test site 2

Test site 3 (Munich)			
	Manual reference		
	Test 1	**Test 2**	**Test 3**
Completeness	**58.6 %**	**66.8 %**	
highways	63.2 %	63.8 %	L-Band
main roads	74.4 %	94.9 %	not
secondary roads	51.1 %	65.2 %	avail-
Correctness	**65.8 %**	**57.2 %**	able
RMS	**2.0 m**	**2.2 m**	
	Topographic map reference		
	Test 1	**Test 2**	**Test 3**
Completeness	**44.6 %**	**50.1 %**	
highways	50.3 %	50.6 %	L-Band
main roads	65.6 %	87.5 %	not
secondary roads	38.8 %	45.7 %	avail-
Correctness	**61.1 %**	**54.1 %**	able
RMS	**3.8 m**	**3.8 m**	
Correctness incl. ways	**73.9 %**	**72.3 %**	

Table 4. Comparison of extraction results to manual extraction of test site 3

For test site 2 (Erfurt) the same set of parameters was used as for test site 1. The proportion of found highways and main roads are approximately the same like in test site 1 or 3. In comparison with optical imagery, it seems that the extraction results on different SAR scenes are less sensitive to parameter settings. This is probably due to the controlled illumination conditions of the radar image acquisition.

Automatic road extraction often fails to extract secondary roads. This is, due to the lower visibility of secondary roads in comparison to main roads in case of the 2 m E-SAR data. In the high-resolution AeS-1 image the completeness of the extracted secondary roads is relatively low, too (65.2 %). But in this case, the scenery is more industrial. Therefore, one longer road occasionally divided by a crash barrier and one extremely wide road were not detected.



(a)

(b)

Figure 3. Highway with impeding traffic signs and bridges; (a) X-HH image, (b) Extracted roads

The correctness of all extraction results tells that about 70 % of the extracted road segments are correct. Most of the false alarms are other dark linear structures like shadows of the borders of forests and hedges between fields' structures or, in some cases, ways.

By incorporating ways into the reference data the correctness increases in case of *test 2* from 71.0 % to 89.4 %. This means that in the scene some ways are detected, which do not belong to the reference data. This phenomenon presents the absence of a classification of automatic extracted results. Unpaved ways could be excluded from the extraction result by integrating a distinction between paved and unpaved ways.

5. CONCLUSION

Automatic road extraction was performed on two large test sites. The extraction results were evaluated based on a comparison with reference data. Quality measures for the completeness, the correctness and the geometrical accuracy were calculated. For this purpose, the reference data were separated into three classes: highways, main roads, and secondary roads, analogous to the German topographic map standard in scale of 1:25,000. The completeness and the geometric accuracy were calculated for each of these classes separately. All these comparisons were carried out using two kinds of reference data: vector data of a digital topographic map and road axes extracted by a human operator. Thus, we take into account which roads are really existent in the scenery and which an operator is able to detect from the imagery. The comparison of the extraction results achieved with three different test set-ups, shows that it is useful to adapt the parameters of the line extraction adequately to the width of the roads to be extracted. Nevertheless, secondary roads could not totally be extracted automatically. But also some of the secondary roads are missing in the manually extracted reference, because they are not visible in the SAR imagery.

A promising approach would be the use of local context information, which could provide additional evidence for roads. In SAR imagery the appearance of roads is often affected by strong scattering objects like bridges, trees, and traffic signs. These local context objects can disturb road extraction but they can also support it. In (Wessel et al.,

2003) we showed that by an explicit modelling and integration of local context objects a more complete road network, especially concerning the classes secondary roads and highways could be extracted.

In total the results are strongly dependent to width and visibility of roads as well as on the scene content (rural or industrial). Presently, for main roads quite satisfying results can be achieved. What is missing in the current implementation of the road extraction is

- an internal evaluation of the extraction results, which would lead to more correct results, and
- a classification of the extraction results into different road classes, such that, e.g., unpaved ways could be excluded from the extraction results.

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