

EVALUATION OF AUTOMATIC ROAD EXTRACTION RESULTS FROM SAR IMAGERY

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ABSTRACT:

Automatic and semi-automatic methods for the extraction of topographic information are a present research topic. Especially for topographic mapping and navigation applications road extraction is important, but still not in practice. Due to the speckle effect and the limited width of roads with respect to the ground resolution automatic road extraction from SAR imagery is rather difficult. In this paper we want to investigate the potential of an automatic road extraction approach of the Technische Universität München, Germany. We apply the road extraction approach to two large test sites and evaluate the achieved results to two kinds of reference data: topographic map data and manually plotted vector data. For this purpose, the reference data are separated into three classes: highways, main roads, and secondary roads. The comparison shows that the extraction results depend on the road classes. Presently, for main roads quite satisfying results can be achieved. Regarding the completeness, highways and secondary roads cannot totally be extracted automatically, due to their width, visibility or a missing model for highways in the present approach.

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). The roads were detected from it 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 (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 the 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 et. al., 1998, 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 road extraction strategy was developed for optical imagery, so we present some modifications to adapt the algorithm to SAR imagery. We carry out extensive experiments on two larger test sites of about 110 km² in total and evaluate the achieved results by comparing the road extraction results to reference data regarding different road classes. Thus, we distinguish between the content of a topographic map and what a skilled operator is able to detect in the data.

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2. EXTRACTION STRATEGY

The extraction strategy is composed of different steps, which are shown in Figure 1. In the following a short description of each step is given, with emphasis on the adaptations made for SAR and for large data sets.

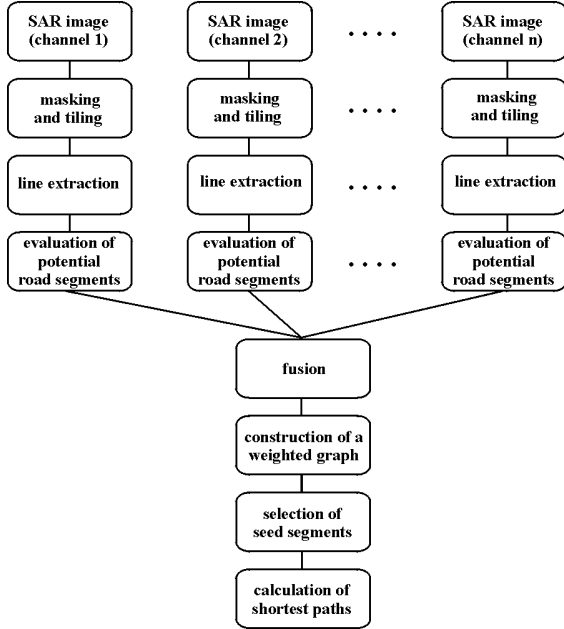


Figure 1. Road extraction workflow

Pre-processing: For the first time, the TUM approach is tested over a larger test site. Therefore, some additional preparing steps are necessary to handle the data. In particular, test site 1 consists of 3 neighbouring 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 (by scaling the grey values with the mean grey value of each column and rescale it to 256 grey values). In order to reduce speckle, we use the multi look, geocoded X- and L-band data.

Same adaptations of the TUM road extraction strategy for optical imagery towards SAR imagery were necessary. As roads in SAR imagery appear as dark lines, it is possible to facilitate their extraction by using directly the intensity of each pixel, instead of only local contrast information. We established this for the time being by a threshold. So, a restriction to the relevant areas can be achieved. The advantage of this restriction is that the parameter settings for the line extraction can be softened and nevertheless, fewer false alarms are extracted.

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). Both masks, the 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 is performed in multiple images of different radiometric and/or geometric resolutions separately using the approach described in (Steger, 1998) which is based on differential geometry. 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.

Potential road segments: In the next step, the lines are evaluated, proportional 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 fuzzy values. An overall fuzzy value for each line is derived by aggregation of the specific values.

Fusion of different image channels: After evaluating the road segments, more global characteristics of roads are considered in terms of the functionality and topology of roads. According to the nature of roads, they form a network wherein all road segments are topologically linked to each other. Thus, the different sub-parts of the test site have to be fused to connect them to each other. Also, the potential road segments of all channels are fused.

Construction of a weighted graph: 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, 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.

3. EVALUATION STRATEGY

The evaluation of the automatically obtained results is done by a comparison to reference data. 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. More details can be found in (Wiedemann, et. al., 1998).

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. It is expressed as RMS difference between the extracted and the reference data.

4. RESULTS AND DISCUSSION

4.1 Test site and data description

The test site covers an area of approximately 110 km². Because the automatic road extraction works well, only in open areas, the test site consists of two rural sceneries in Germany: test site 1, Ehingen, south Germany, covers about 7.5 km × 11 km and test site 2, Erfurt, east Germany, represents land coverage of about 40 km². The test data set consists of airborne X-band and fully polarimetric L-band data taken by the experimental SAR (E-SAR) of the German Aerospace Center (DLR) within the Prosmart II project. The ground resolution is about 2 m, respectively 3 m with pixel spacing of 1 m. The missions took place in September 2000 and March 2001. Each test site is composed of three tracks.

The SAR imagery contains highways, main roads, and different types of secondary roads. The distinction between different secondary roads is more formal, so they were grouped to one class of secondary roads. Figure 2 shows the composed, geocoded, multi look SAR image (X-band, HH-polarization) of test site 1 with the arranged topographic map reference data. The main roads comprise two wide lanes. They are displayed with a thick white line. The thin white lines are two-lane secondary roads. Highways are only contained in test site 2, they consist of four or more lanes separated by a crash barrier.

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 taken in 1995 and verified in a field completion in 1998. The geometric accuracy is about 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 data. Since the automatic road extraction only works well in open areas city streets and forest roads are excluded from both references like in the extraction.

4.2 Road extraction results

The tests are carried out on X-HH, X-VV, and L-VV band. Extractions are made on single- and multi-channel data, see Table 1. The first result was generated using X-band data with horizontal polarization (X-HH). The second result was achieved based on the X-HH data, as well, but in this case in addition to wider lines, also narrow lines were extracted during the line extraction step. The third extraction result was achieved with the aid of a multi-frequency and multi-channel data set by extracting from X-HH, X-VV, and L-VV. By visual inspection, we found out that roads are most clearly visible in the L-VV channel, compared to all the other polarimetric L-band channels.

	number of channels	bands	line width
Test 1	1	X-HH	wide
Test 2	2	X-HH	wide
		X-HH	narrow
Test 3	3	X-HH	wide
		X-VV	wide
		L-VV	wide

Table 1. Test overview

The three tests have been carried out on each of the two test sites. Two smaller subsets of test site 1 are chosen to optimize the parameter settings. Test site 2 was processed, using the same set of parameters as for test site 1. The results were evaluated using the topographic map data as well as the manually plotted reference data. With regard to the main roads the manually plotted reference corresponds mostly with the topographic map data. In contrast, secondary roads could not totally be gathered during the manual extraction of the reference data. The evaluation was carried out for each category of roads separately. The resulting quality measures are summarized in Table 2- 4.

First analyzing the overall results of the two 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 the secondary roads are relatively complete, which is a consequence of the additional extraction of narrow lines in test 2. But nevertheless, automatic road extraction often fails to extract secondary roads. This is, due to the course visibility of secondary roads in comparison to main roads.

	Manual extraction		
	Test 1	Test 2	Test 3
Completeness	68.2 %	76.4 %	61.1 %
main roads	92.7 %	89.9 %	83.8 %
secondary roads	59.6 %	71.6 %	53.2 %
Correctness	55.2 %	56.4 %	46.2 %
RMS	2.1 m	2.0 m	2.2 m
main roads	2.2 m	2.2 m	2.2 m
secondary roads	2.1 m	1.9 m	2.2 m

Table 2. Comparison of extraction results to manual extraction of test site 1

	Topographic map		
	Test 1	Test 2	Test 3
Completeness	55.4 %	65.8 %	50.9 %
main roads	90.9 %	88.1 %	82.5 %
secondary roads	45.5 %	59.6 %	42.1 %
Correctness	53.8 %	57.9 %	46.0 %
RMS	3.0 m	2.9 m	3.0 m
main roads	3.5 m	3.4 m	3.8 m
secondary roads	2.7 m	2.6 m	2.7 m

Table 3. Comparison of extraction results to topographic map data of test site 1

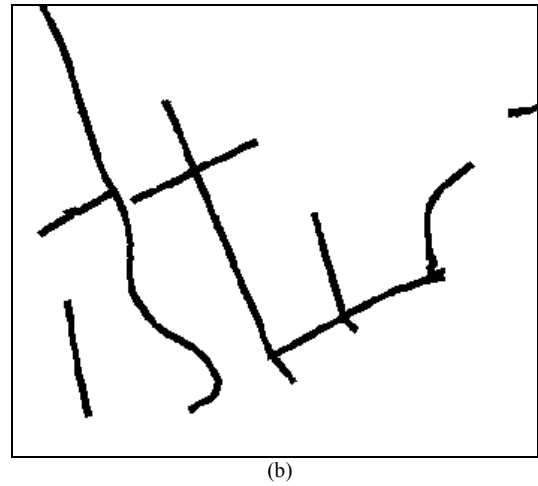
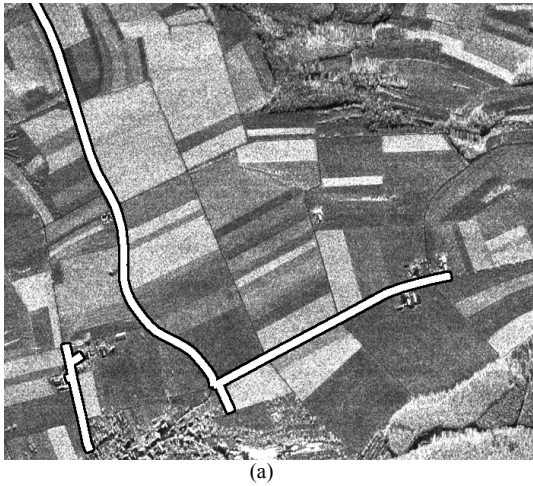


Figure 2. Extracted ways (b), which are not contained in the reference road network (a)

The extraction results for test site 1 are displayed in Figure 3. The correctness of all extraction results tells that only half 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 56,9 % to 79,0 %. In Figure 4 a scene is shown where ways are detected, which do not belong to the road network. This phenomenon presents the absence of a classification of automatic extracted results. Ways could be excluded from the extraction result by integrating a distinction between, e.g., paved and unpaved ways.

The proportion of found main roads is relatively high, contrary to highways. Though highways in the test site 2 are clearly visible, the result of the automatic road extraction is very incomplete for this road category. This is because especially crash barriers, traffic signs, bridges, and low contrast impede the extraction. To improve the results, highways have to be explicitly modeled, which is not the case in the current implementation of the road extraction. A first step could be the modeling of the crude crash barrier and its surrounding.

	Manual extraction		
	Test 1	Test 2	Test 3
Completeness	45.6 %	59.4 %	50.5 %
highways	35.4 %	68.3 %	52.9 %
main roads	88.8 %	94.1 %	92.5 %
secondary roads	39.5 %	46.1 %	38.5 %
Correctness	42.8 %	56.9 %	42.7 %
RMS	2.1 m	1.9 m	2.2 m
highways	2.5 m	1.7 m	2.3 m
main roads	2.0 m	2.0 m	2.1 m
secondary roads	2.0 m	2.0 m	2.1 m

Table 4. Comparison of extraction results to manual extraction of test site 2

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 relatively exact to 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 fully polarimetric SAR data since they could provide more information about the surface than only single-polarization data. Especially for modeling the single bounce surface characteristic of roads, the odd bounce component of the Pauli decomposition could be valuable.

In total the results are related to width, visibility, and modeling of each class. Presently, for main roads quite satisfying results can be achieved. What is missing in the current implementation of the road extraction is

- an explicit modeling of highways, which would improve the completeness of the extraction results, concerning this class of roads,
- 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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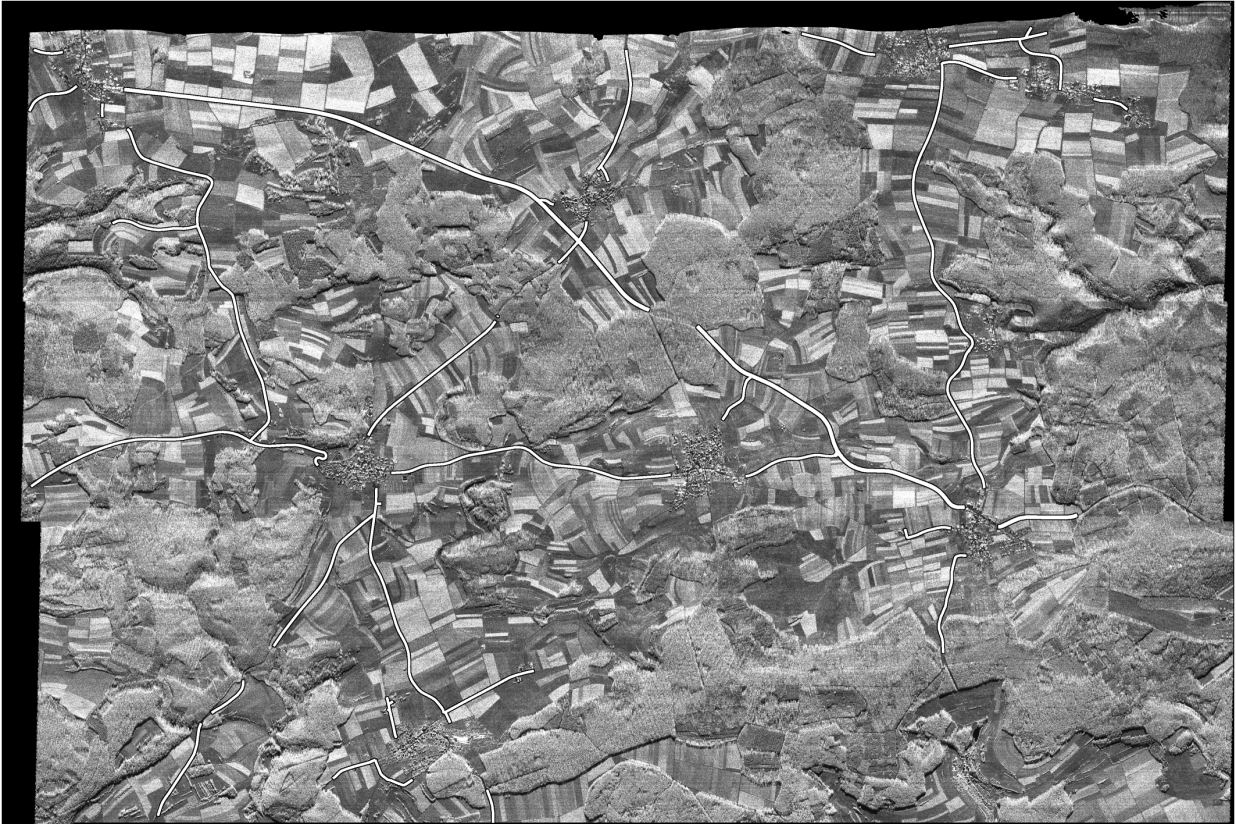


Figure 2. Test site 1 with topographic map reference data

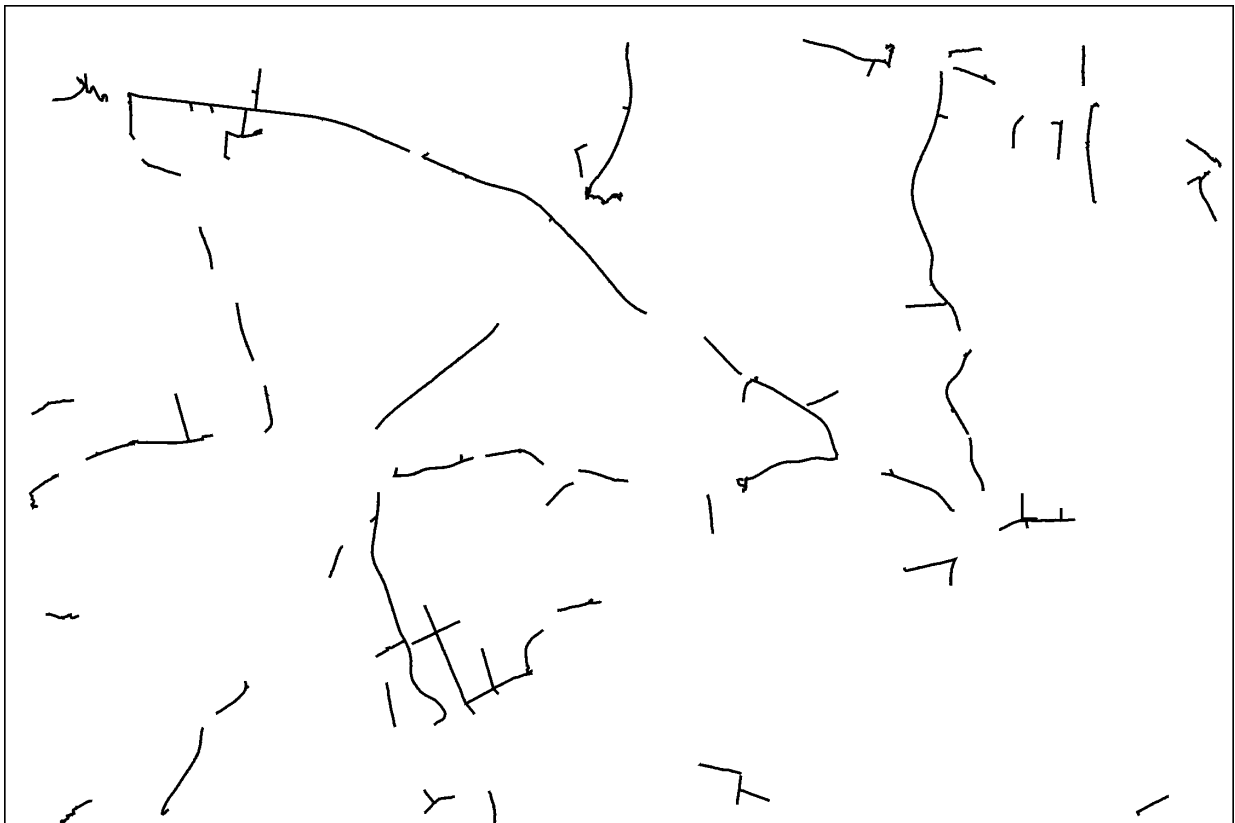


Figure 3. Road extraction result of test 2 (extraction with two line widths)