IMPROVEMENT OF ROAD CROSSING EXTRACTION AND EXTERNAL EVALUATION OF THE EXTRACTION RESULTS

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ABSTRACT

The extraction of road crossings is often neglected by systems for automatic road extraction. Frequently, crossings arise as by-products of the grouping step. This leads to geometrical inaccuracies and visually and cartographically unsatisfactory results. In this paper, an approach for the improvement of extracted road crossings is presented as well as a method for the external evaluation of the extraction results.

1 INTRODUCTION

Until now, there are just a few papers, which deal with the explicit modeling of road crossings in the context of automatic road extraction. The problem for the extraction of road crossings lies mostly in their great variability. Therefore, less knowledge can be used for the extraction of crossings, compared with the extraction of roads: E.g., disturbances like shadows can be detected or at least bridged during road extraction based on the knowledge that the roads are straight with parallel road sides. In contrast, during the extraction of crossings, often, disturbances cannot be detected because of the weaker geometric constraints. Two papers, which deal with road crossing extraction are presented in the following:

(Teoh and Sowmya, 2000) use a rule based system for the detection of road crossings in aerial images. The rules concern attributes like the number of discharging roads, differences in gray values, width, and direction of these roads, as well as their distance from each other. The domain of these parameters is determined from reference data. Due to the fact that, until now, only a few tests were carried out, no rating of this approach is possible.

In (Boichis et al., 1998, Boichis et al., 2000), a knowledge based system for the extraction of road crossings from aerial images is presented. Hypotheses for crossings as well as for their formation of main roads and branching roads are determined from GIS data and verified based on the image data. In particular, special crossing types as roundabouts or splitting roads are modeled. The presented results are very promising. A weakness of this approach is that the image information is not fully exploited, especially for the determination of the geometry of the branching roads.

Internal evaluation (self-diagnosis) and external evaluation of the obtained results are of major importance for the relevance of any automatic system for practical applications. Obviously, this statement is also true for automatic image analysis in photogrammetry and remote sensing. However, so far only relatively little work has been carried out in this area. This is mostly due to the moderate results achieved. Only recently automatic systems reached a state in which a systematic evaluation of the results seems to be meaningful. This led to an increased notice of the importance of the evaluation of extraction results (Ruskoné, 1996, Phillips et al., 1997, Bowyer and Phillips, 1998, Wiedemann et al., 1998, Shufelt, 1999, DAGM-WG, 2001, ISPRS-WGIII/8, 2002).

In the following chapter, the approach for the improvement of the road crossing extraction is presented. In chapter 3 the evaluation of the extraction results is described. Results are presented in chapter 4. The paper concludes with a summary and an outlook.

2 IMPROVEMENT OF ROAD CROSSING EXTRACTION

In many road extraction systems, crossings are not explicitly modeled. This leads to weaknesses of the extraction results at and near crossings. Especially, the approach of (Wiedemann and Hinz, 1999), delivers sometimes cycles instead of crossing points (see fig. 1). Since crossings are an elementary part of the road network, it is necessary to improve these faulty extraction results.
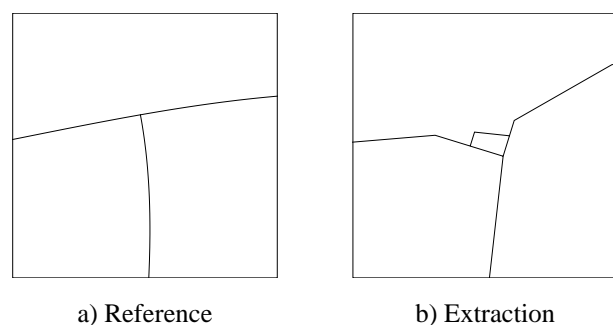

a) Reference   b) Extraction

Figure 1: Incorrect extraction result at a junction

2.1 Modelling of Road Crossings

Road crossings are points of the road network, at which three or four roads segments are connected with each other. Crossings connecting just three roads segments are often called junctions. It is assumed that at least two road segments are connected such that they form a continuous road, which can be traveled on with more or less undamped speed. In the following, each such continuous road is

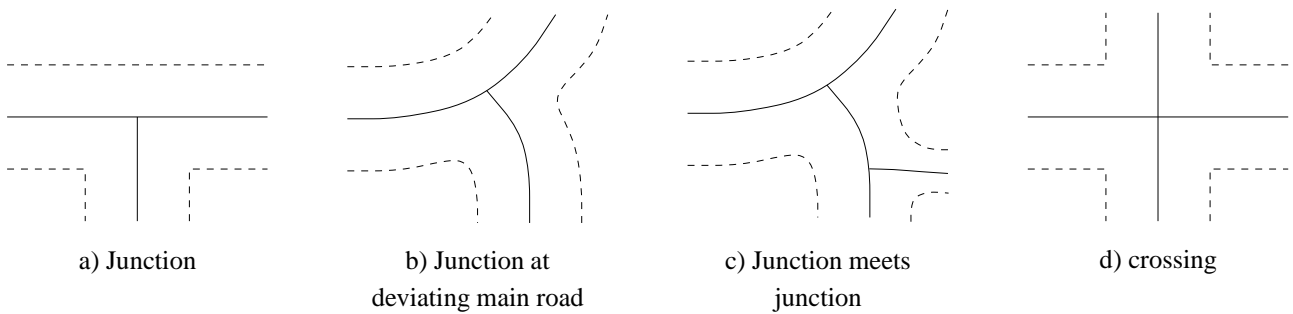| a) Junction | b) Junction at deviating main road | c) Junction meets junction | d) crossing |

Figure 2: Examples for junctions and crossings (road center lines: solid lines; road sides: dashed lines)

called **main road**, all the other road segments are called **branching roads**. The center line of a main road runs in the middle of the main road — regardless of any branching road. The center line of a branching road meets the center-line of a main road or that of another branching road more or less orthogonal. Examples for road crossings, which comply to the described model are given in Fig. 2.

2.2 Reconstruction of topology

The aim of the reconstruction of the topology is, to detect and to remove all cycles within the crossing area. Of course, if the road extraction result does not contain such faulty cycles, this step is not necessary.

For the elimination of faulty cycles within crossing areas, at first, all minimum cycles within the road network are determined. Only such cycles are selected, which enclose a small area. Cycles having a common edge are joined into one cycle by deleting this edge. All nodes of the cycle that are incident with at least one edge, which do not belong to the cycle are called border nodes. To eliminate the cycle, all edges and nodes of the cycle, except its border nodes, are deleted. Then, a new node, the preliminary crossing point, is inserted and connected to all border nodes by edges. The coordinates of the preliminary crossing point can, e.g., simply be set to the mean coordinate values of all border nodes.

2.3 Reconstruction of geometry

Because it is not known beforehand, which road segments form a main road and which are branching roads, for each crossing, all combinations of main roads and branching roads, which are possible according to the given road segments and the above described crossing model, are generated and evaluated. The main roads and the branching roads result from a smoothing of the extraction results, whereas the image data is used to improve the geometry of the main and branching roads if the extraction result is uncertain. The combination of main roads and branching roads that reaches the best score during the evaluation procedure, is selected as the final road crossing. It is inserted into the road network instead of the preliminary crossing.

2.3.1 Main roads In the vicinity of crossings, main roads are represented as curved segment, described by a parameterized cubic curve. As a main road consists of two road segments, both road segments are approximated together by *one* curved segment. The determination of the

curved segment is carried out by a least squares adjustment. If the road segments contain uncertain parts, e.g., parts where no image information was used during the road extraction, now, image information is used for the determination of the curved segment.

Of course, the main roads are part of the whole road network. Therefore, the first and the last point of the main roads are fixed. As the directions in these points may be erroneous, these directions are not used to fix the direction of the main road in the start and the end point. This may lead to points of discontinuity, which could be eliminated by a subsequent smoothing.

2.3.2 Branching roads The determination of branching roads is carried out similar to the determination of main roads except for two main differences: (1) Each branching road consists of only *one* road segment, (2) Each branching road meets another main or branching road more or less orthogonal.

For the realization of the condition that a branching road meets another road, the adjustment model has to be adapted as follows: The starting point of the branching road is not fixed but lies on the other road. The position of the starting point on the other road is estimated within the least squares adjustment.

2.3.3 Evaluation of the different crossings The evaluation of the main roads is based on the following attributes:

- Mean curvature
- Mean change of curvature
- Homogeneity of gray values along the center line

Linear fuzzy functions are used to transform these attributes into preliminary fuzzy values.

The evaluation of the branching roads is based on the same attributes as the evaluation of the main roads. In addition, the direction difference between the branching road and the main road is taken into account. The attributes of the branching roads are transformed into preliminary fuzzy values, as well.

An overall fuzzy value for each main road and each branching road is derived by aggregation of its respective preliminary fuzzy values using the fuzzy *and* operator (Zadeh, 1989).

The final quality measure of each possible crossing is calculated by a weighted mean of the fuzzy values of the respective main and branching roads.

The crossing having the best final quality measure is inserted into the road network instead of the preliminary crossing.

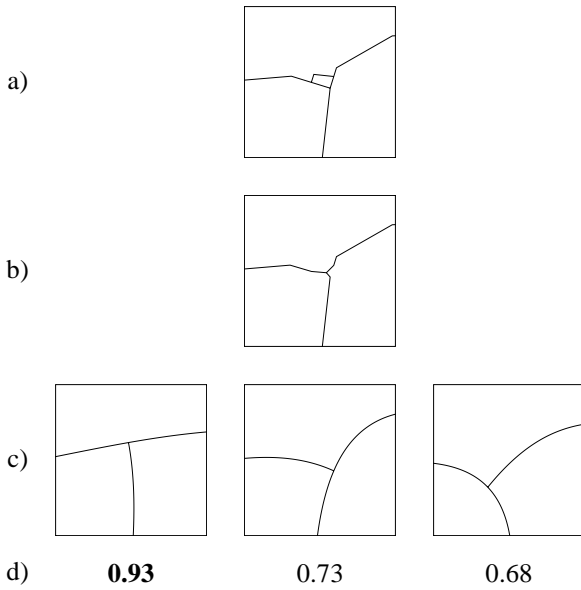In Fig. 3, the whole improvement process is shown for the junction displayed already in Fig. 1b.

Figure 3: Example for the improvement of a junction. a) Incorrectly extracted junction; b) Topologically corrected junction; c) All possible combinations of main roads and branching roads; d) Quality measures for the above junctions (0: bad, 1: good)

3 EXTERNAL EVALUATION OF ROAD CROSSINGS

The proposed quality measures aim at assessing exhaustivity as well as geometrical accuracy. They address the following questions: (1) How complete is the extraction, (2) How correct, and (3) How accurate is it.

The evaluation is carried out by comparing the automatically extracted road crossings with manually plotted road crossings used as reference data. The evaluation is processed in two steps: (1) Matching of the extracted road crossings to the reference data and (2) Calculation of quality measures. Each step depends on the other: the less tolerant is matching, the less exhaustive the extraction is considered to be, but the more accurate it looks. Therefore, matching is an important part of the evaluation process.

3.1 Matching

For the matching, the crossings are considered as point features. Therefore, the matching of the extraction result to

the reference data can be carried out quite simple: If the distance between the extracted crossing and the reference crossing is below a predefined threshold (buffer width), the extracted crossing is assumed to be matched, i.e., it is assumed to be correct.

3.2 Definition of Quality Measures

The following quality measures are proposed:

- Completeness

$$= \frac{number\ of\ matched\ reference\ crossings}{number\ of\ all\ reference\ crossings}$$

The completeness ($\in [0;1]$) is the percentage of the reference data, which is explained by the extracted data
The optimum value for the completeness is 1.

- Correctness

$$= \frac{number\ of\ matched\ extracted\ crossings}{number\ of\ all\ extracted\ crossings}$$

The correctness ($\in [0;1]$) represents the percentage of correctly extracted road crossings with respect to all extracted road crossings.
The optimum value for the correctness is 1.

- Redundancy

$$= \frac{MC^{Extr} - MC^{Ref}}{MC^{Extr}}$$

with:
MC^{Extr} = number of matched extracted crossings
MC^{Ref} = number of matched reference crossings

The redundancy represents the percentage of multiply correct extracted road crossings.
The optimum value for the redundancy is 0.

- RMS difference

$$RMS = \sqrt{\frac{\sum_{i=1}^{l}(d(extr_i; ref)^2)}{l}}$$

l = number of matched extracted crossings

$d(extr_i; ref)$ = shortest distance between the i-th matched crossings and the corresponding reference crossing

The RMS difference ($\in [0; buffer\ width]$) expresses the average distance between the matched extracted and their corresponding reference crossings, and thus the geometrical accuracy potential of the extraction.

4 RESULTS

The improvement of the road crossing extraction was applied to road extraction results of the approach presented in (Wiedemann and Hinz, 1999), which was applied to an
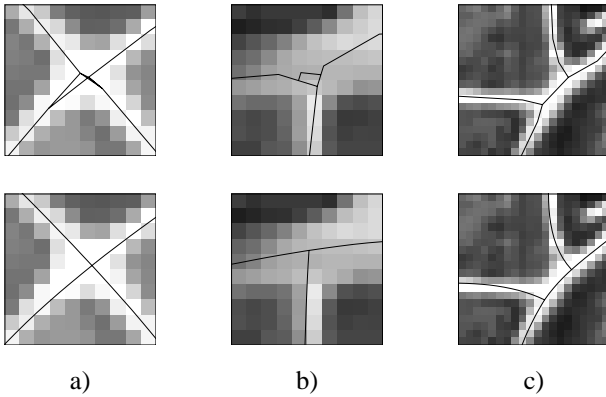
Figure 4: Examples for the improvement of road crossings (top: before improvement; bottom: after improvement)

image with a ground pixel size of 2 m. In Fig. 4, the results are displayed for three different crossings. They show that the extraction result of each crossing could be significantly improved.

Table 1 shows the results for the whole test scene. The increased correctness and the better geometric accuracy (RMS) of the improved crossings underline the potential of the approach to improve the geometry of the extracted road crossings. Crossings which were extracted geometrically wrong in the first place now match the reference data. The redundancy which was 53 % in the first place could be brought down to 0 %. This proves that the topological improvement, i.e., the elimination of cycles, works well. Only the completeness of the improved result becomes a little bit worse, as some crossings were reconstructed geometrically wrong. In most cases, this is caused by geometrical inaccuracies of the extracted road center lines to which the main and branching roads are fixed at their end points.

	Before improvement	After improvement
Completeness	69 %	64 %
Correctness	59 %	82 %
Redundancy	53 %	0 %
RMS	4.5 m	4.1 m

Table 1: Evaluation results

5 SUMMARY AND OUTLOOK

In this paper, an approach for the improvement of extracted road crossings was presented as well as a scheme for the external evaluation of the extraction results.

The crossing model comprises relatively simple but commonly used crossing types. Up to now, in the work presented in this paper, the following crossings are not modeled: Roundabouts, crossings connecting more than four road segments, and complex crossings with overpasses etc. Especially the modeling of complex crossings would be very interesting and could improve the road extraction results in these areas.

Further quality measures could evaluate the number of road segments, which are connected by the crossing as well

as their directions. If a more detailed modeling and extraction of crossings, e.g., based on lanes is available, also a more detailed evaluation will be possible and necessary.

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