EFFICIENT METHODS AND INTERFACES FOR ROAD TRACKING

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Commission III, WG III/4

KEY WORDS: Road Extraction, Semi-Automatic, Road Tracking, User Interface

ABSTRACT:

In this paper, we present a prototype system for semi-automatic extraction of road axes and a study on its efficiency for operational use. The core of our system is a road tracker based on profile matching. This road tracker is enhanced with a graphical user interface that guides the operator through the whole data acquisition process. For typical tasks and problems that occur during the extraction process the system provides road specific options for interaction. I.e., the system monitors the behavior of the tracking module, identifies problems, reports information to the operator, and if necessary asks the operator for his decision or action. In order to evaluate the efficiency of our system we compared it to manual plotting of road axes.

1. INTRODUCTION

There is a strong demand to automate acquisition and update of road data. Despite a lot of research work on semi- and fully automatic approaches for road extraction, the desired high level of automation could not be achieved by now. The main problem of fully automatic approaches is that for many applications the quality of the results is not sufficient. Some parts of the road network are missed, and some parts are erroneous. E.g., looking at the results of our approaches (Hinz et al., 2000) there is still a need for quality control and manual post editing. Therefore, the overall benefit of automatic systems depends not only on their sophisticated algorithms but also on adequate tools for post editing. Semi-automatic, i.e., user-assisted, systems have the advantage, that the quality of the results is guaranteed, because a human operator controls the data acquisition process and prevents errors on-line. Of course, the algorithms for semi-automatic road extraction do not need to meet the same requirements as those for fully automatic systems. An efficient user interface and fitting the semi-automatic tools into the data acquisition process becomes very important. Whereas, requirements for a detailed and explicit road model, which is necessary for full automation, are quite low.

At the moment, fully automatic approaches must still be regarded as a subject of basic research, and they seem not to be able to find their way into operational work flows in the near future. On the contrary, semi-automatic approaches seem more likely to be useful in operational applications. Quite a lot of promising approaches for semi-automatic road extraction have been presented and analyzed in the last decades, e.g., (Groch, 1982), (McKeown and Denlinger, 1988), (Vosselman and de Knecht, 1995), (Neuenschwander et al., 1995), (Grün and Li, 1997), or (Dal Poz et al., 2000).

Two groups of approaches can be distinguished: Road trackers and path optimizers. Road trackers need a starting point on the road and a second point to define the direction of the road. Path optimizers are designed to find an optimum path between two points on a road. (Airault and Jamet, 1995) report on comprehensive tests of the operational use of their semi-automatic road extraction process and come to the conclusion that it could be interesting to implement semi-automatic methods even if the saved time does not correspond to what people are expecting from automation. However, up to now none of proposed approaches found its way into operational applications on a large scale.

In this paper, we present a system for semi-automatic road extraction and study its efficiency compared to manual plotting. The system employs a road tracking algorithm based on profile matching. Tracking algorithm and user interface are described in Sect. 2. In Sect. 3 we discuss some characteristics of our approach. Section 4 summarizes the results of our study. In Sect. 5 we draw some general conclusions.

2. SYSTEM

The basic idea is to leave the task of road detection to the operator, and to focus the automation on the measurement of the road axes. From the user point of view the procedure is as follows: The operator has to identify a short part of a road axis. This road part serves as initialization for an automatic tracking tool. Whenever the internal evaluation of the tracking tool indicates that the tracker might have lost the road axis, it demands for interaction of the operator. Then the operator has to confirm the tracker or he must edit the extracted road and put the tracker back on the road.

Our tracking algorithm is in the style of the approach of (Vosselman and de Knecht, 1995) and in some points it bears resemblance to (Groch, 1982) and (McKeown and Denlinger, 1988). As (Vosselman and de Knecht, 1995) we employ matching of gray value profiles and, in order to make the tracking more robust, we fuse the results of the profile matching with the prediction of the next road position. Compared to

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(Vosselman and de Knecht, 1995) there are some simplifications concerning the underlying road model but also some extensions, e.g., the simultaneous use of multiple channels, handling of small local changes in the appearance of the road. Special attention was paid on making the tracking algorithm reliable and on keeping the number of relevant parameters low. A user interface with specific menus was designed to make the correction of tracking errors fast and convenient. However, the interface mainly incorporates basic functionalities, which are generic and useful for any tracking tool.

2.1 Automatic Road Tracking

The tool for automatic tracking of the initialized road carries out the following steps:

a) Generate a *reference profile*, i.e., a typical gray value profile perpendicular to the road axis.
b) Predict next position of the road axis and match reference profile with profile at new position (*search profile*).
c) Estimate position of next point on the road by weighting prediction (derived from previous direction of the road) and correlation (cross correlation of reference and search profile).
d) Check whether any stopping criterion is fulfilled. In case of problems, e.g., in case of multiple poor matches or when approaching to an already extracted road, exit automatic tracking and proceed with e). Otherwise, proceed with b).
e) Stop automatic tracking, report reason for stop to the operator, and offer choice of appropriate interactions.

As mentioned above the tracking algorithm is initialized by the operator. The human operator measures the first segment of a road with two mouse clicks (Fig. 1, left). With a third mouse click the length of the reference profile is defined (Fig. 1, right). The reference profile corresponds to the average of all gray value profiles perpendicular to the first segment of the road. From these profiles also an estimation of the width of the road can be derived.

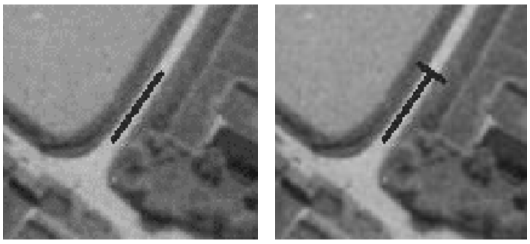

Fig. 1: Interactive initialization.

The prediction of the road direction is based on the previous course of the road. Prediction is necessary to define the search profile for the next point of the axis. The suitable size of the increment, i.e., the distance between two points on the road axis, can be estimated roughly from the width of the road, and is not a critical parameter.

The search profile is taken at the predicted position. Similar to the computation of the reference profile, we derive the search profile from a weighted average of multiple profiles in the surrounding of the predicted position. With this the influence of small disturbances and noise is reduced. Furthermore, the search profile must be long enough to allow also for the detection of significant changes in road direction. Then cross correlation between search and reference profile is computed and the best match is regarded as observation for the position of the new point on the road axis.

Due to the disturbing influence of cars, trees, or other objects and due to variations in the gray value profile of the road it is not sensible to rely on the observation only. Therefore, in the next step we fuse the results of the profile matching and the prediction. The final position of the new point is a weighted average of the predicted point and a shift of this point perpendicular to the predicted direction of the road. The mathematical model for this fusion is taken from the theory of Kalman filtering, i.e., the weighting depends on the accuracy of prediction and observation. However, a rigorous application of Kalman filtering turned out to be difficult, because reasonable estimations for the accuracy of the observation, i.e., of the matching, are not available. Least squares matching seemed to be too optimistic, and cross correlation does not deliver accuracy numbers. To cope with this problem we applied a simple heuristic function to transform the coefficient of correlation into an accuracy value for the observation.

In some cases the tracking tool should give control back to the operator, ask for confirmation, and accordingly allow for user interaction. Two groups of reasons to stop the tracking algorithm can be discerned. First, the tracker approaches the border of the image or another already extracted road axis. Second, the tracker is no more confident of being on the road. For the latter case the tracker needs some kind of internal evaluation. On the one hand, it suggests itself to employ the results of the Kalman filter. Ideally, a threshold on the accuracy of the estimated position could be used. However, in our case this is not feasible, because the accuracy numbers delivered by the fusion process are biased due to the above-mentioned heuristics. On the other hand, it is obvious that the reliability of the position of the road axis drops in case of multiple consecutively low correlation coefficients. Therefore, we decided to introduce a correlation threshold and count the number of poorly correlated profiles. The counter increases with every poor correlation. In case its current value is higher than 0, then it decreases with every good correlation. If this counter exceeds a certain threshold then the tracker stops. The number of poorly correlated profiles, which is tolerated, can be calculated based on considerations about the maximum extent of local disturbances on the road.

Additionally, we enhanced the tracking tool with some optional modes. E.g., the tracking algorithm is allowed to update the reference profile in order to cope with radiometric variations caused by different brightness within the image or by changes in the surface material. In case the tracker is applied to an orthophoto then it is able to collect simultaneously the height from the corresponding digital terrain model (DTM). Furthermore, differences between search and reference profile are analyzed and small segments with “outliers” are masked in the search profile. With this the cross correlation becomes less sensitive to local disturbances. In addition, for each road axis the width is estimated in a robust manner. At the end, the extracted road axes are smoothed and then the number of points is reduced by means of polygon approximation.

2.2 Interaction

According to the characteristics of the system specific possibilities for interaction and editing must be provided. Some are closely related to the strengths and deficiencies of the tracking algorithm. Others are more generic and can be considered as common GIS-functionalities, e.g., tools for image processing or for handling and displaying the road data. A quite comprehensive set of necessary or useful tools can be found in (Airault and Jamet, 1995). To enable an efficient use of the automatic tracking tool the graphical user interface of our prototype consists of three windows (see Fig. 2). The overview window displays the entire image to be processed and the already extracted roads. The zoom window displays a part of the image at original resolution including the last points of the currently plotted road axis. The window at the bottom is used to display messages about the current status of the tracker and for instructions to the operator. Additionally, pop-up windows appear in case the tracking algorithm stops.

Fig. 2: Graphical user interface

Interaction is required mainly if the internal evaluation indicates a possible failure of the tracking module. Depending on the reason for the stop a specific menu-window pops up and asks the operator to select the appropriate menu item. To make the "trouble shooting" more convenient for the operator the most likely action is marked. In ideal case the operator can confirm the suggested action with only one mouse click, e.g., decide about connecting or merging different roads or accept an extracted road axis.

There will always occur situations where the tracking algorithm is not able to follow the road and a lot of interaction would be necessary to correct its failures. Therefore, the operator can easily switch between manual and automatic plotting. The amount of interaction also depends on the parameter setting of the automatic tracking tool. To allow for fast influence on the behavior of the tracking algorithm some parameters and options can be changed online, i.e., not only at the start of the program. This is especially useful if the tracking using the default parameters does not yield satisfying results. Furthermore, we tried to keep the meaning of the parameters easy to understand and easy to tune - also for those who do not know details about the implementation.

Changes in the behavior of the tracking algorithm are not likely to raise the need for a redesign of this interface. Yet, the integration of other semi-automatic methods, e.g., snakes, or parts or our fully automatic approaches like (Baumgartner et al., 1999) or (Wiedemann and Ebner, 2000), would probably necessitate changes in the extraction strategy and in the user interface, too.

3. DISCUSSION

The proposed tracking algorithm employs a very simple road model. In fact, it does not really track roads but an arbitrary gray value profile defined by the user. But exactly that makes the algorithm flexible to track almost every road, and it is not restricted to bright or dark roads or to roads of a certain width. The tracker works well if the profile contains prominent features, e.g., strong edges caused by the roadsides. If the operator would initialize the tracker on any arbitrary linear feature, for example on the boundary between two fields, then the tracker would not be able to recognize that it does not follow a road. Problems would occur only for road specific tasks, e.g., for the estimation of the road width. However, even such a simple profile-tracking tool is useful for less complex scenes, i.e., rural areas. An important advantage of the current implementation is that there are only a few parameters, which have to be set by the user.

Tracking is successful even for curved roads. Most stops of the automatic tracking tool occurred at intersections. This can be explained by the fact that the gray value profile of roads in intersection areas is often quite different from the typical profile. Figure 3 shows an example for an automatically tracked road. The road has been initialized at the upper left end. The tracking algorithm did not ask for interaction till it reached another road (lower right end).

Fig. 3: Example for automatically tracked road

Since the tracking is carried out in a single image, only the position of the road axis is measured. However, in case of an orthophoto and a DTM the tracker delivers the road axes in 3D. Additionally, we made some tests to integrate DTM information into the tracking algorithm, e.g., putting constraints on the slope of the road. But this did not result in a more reliable extraction, probably due to low resolution of the DTM. The use of multiple channels can help to reduce the amount of user interaction, and it does not slow down the speed of the tracker noticeably. However, tests on color images did not reveal significant improvements compared to tracking in grayscale images.

The tracking algorithm is very fast (Pentium III, 450 MHz), even if it tracks roads in multiple channels simultaneously, and there is not much time of inactivity for the operator. On state-of-the-art computers the automatic tool is even too fast, and it should be slowed down; otherwise the operator could have problems to control the automatic tool.

4. EVALUATION

To quantify the benefit of the described system we compared the time needed for pure manual plotting with a commercial system to the time needed with our system. This test was performed on multiple gray scale images. The resolution of the images varied from 0.2 m to 3 m. The user's task was to digitize the whole road net, i.e., axes of all roads and paths including junction points.

Neglecting the time for data handling, geo-coding, and so forth, we experienced a reduction in plotting time of up to 50% depending on the complexity of the scene. For most rural scenes the time effort was reduced to 50%-70%. For more complex scenes, i.e., for urban or suburban areas, the performance of the tracking tool was too poor to be useful. In urban areas the automatic tracking failed very often, and putting the tracker back on the road every few seconds is quite annoying and time consuming. Nevertheless, the time needed for pure manual extraction can be regarded as an upper bound for the time needed with our semi-automatic system, because the system enables fast switching between automatic and manual road extraction. Since the users got only a brief instruction on the system, they can be considered as almost untrained users. Therefore, for less complex scenes even better rates than 50% can be expected. Further increase in efficiency could be achieved by improvements of the tracking algorithm itself.

In general, the quality of the results of manual and semi-automatic plotting is equivalent, since the operator supervises the results of the semi-automatic system and failures are edited online. On average the geometric accuracy is comparable, too. Visual inspection showed that the results derived with the semi-automatic system are slightly worse in intersection areas but more accurate for curved road parts, since operators tend to set fewer points and therefore sometimes cut off curves.

It turned out that the image resolution could be quite important for the benefit from the automatic tracking tool. In some cases results would have been better if the tracking algorithm was not applied to the original resolution but to a reduced resolution. In the tests the tracker performed best on resolutions of 0.5 m to 1 m. However, the performance also depends on the type of road to be tracked, i.e., for highways or small paths other resolutions might be better.

5. CONCLUSIONS

According to the mainly positive experiences of our study the proposed approach for semi-automatic road extraction seems to be suitable to speed up extraction of roads in rural scenes. The results of our tests are promising. The time effort can be reduced significantly. However, high expectations on automation might still not be satisfied with 50%, because this percentage refers to the plotting time only and not to the overall project time. Unfortunately, in complex scenes there is almost no benefit from the described automatic tracking tool. Concerning more complex scenes, the good thing is that the current tracking tool is very fast, and we could easily allow for more sophisticated models and algorithms. Yet, the use of more sophisticated algorithms would probably raise the number of parameters to be set by the user, and this contradicts the idea of keeping it simple for the user.

For semi-automatic systems sophisticated road models are not the most important issue. An efficient user interface and a good guidance of the operator's actions is much more important. The proposed user interface with overview window, zoom window, and pop-up windows turned out to be very useful. With the overview window the operator can navigate quickly through the whole image and he can see the already extracted roads. The zoom window is used for detailed supervision of the tracking algorithm and for manual measurement. The pop-up windows containing a specific choice of menu items help the operator to select an appropriate action. Especially for untrained users this is very helpful. Furthermore, in an operational system post editing tools, e.g., for selection and correction of road segments and/or single points, would be necessary as well.

Acknowledgements

Ralf Schmid has implemented major parts of the system in the course of his diploma thesis. His work was funded partly by ESG GmbH, Munich.

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