ACTIVE TESTING AND EDGE ANALYSIS FOR ROAD CENTRELINE EXTRACTION

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ABSTRACT:

As in the foreseeable future a human will be expected to remain as part of the object extraction system, semi-automated road extraction methods are still important. Following this trend, this paper presents a semi-automated method for extracting road segments from medium- and high-resolution images based on active testing and edge analysis. The method is based on two sequential and independent stages. Firstly, an active testing method is used to extract an approximated road centreline, which is based on a sequential and local exploitation of the image. Secondly, an iterative strategy based on edge analysis and the approximated centreline is used to measure precisely the road centreline. Based on results obtained using a medium-resolution test image, the method seems to be very promising. In general, the method prove to be very accurate whenever the roads are characterised by two well-defined anti-parallel edges and robust even in the presence of larger obstacles, as e.g. trees and shadows.

1. INTRODUCTION

Road extraction is still a challenging issue of research in the field of digital photogrammetry. The common criterion to classify the extraction schemes is human intervention. In semi-automated methods an operator provides, for example, a starting point plus direction and width to allow the road-tracking algorithm to extract sequentially the entire road (McKeown and Denlinger, 1988; Vosselman and de Knecht, 1995). Fully automated methods attempt to completely circumvent human intervention during the extraction process. Basically, automated methods require a skilful integration of contextual information and *a priori* knowledge into the road extraction task. A sophisticated example is found in Baumgartner et al. (1999), in which different resolutions, grouping, and context are used to extract road network from high-resolution images.

As in the foreseeable future a human will be expected to remain as part of the object extraction system, semi-automated road extraction methods are still important. Following this trend, this paper presents a semi-automated method for extracting road segments from medium and high-resolution images, which is based on two sequential and independent delineators, i.e., the active testing delineator and the edge analysis delineator.

Section 2 presents the active testing method for approximate road delineation. Section 3 presents a strategy to refine previous extracted road centreline using edge information. In Section 4 is presented preliminary results. Finally, conclusions are provided in Section 5.

2. ROAD DELINEATION USING ACTIVE TESTING STRATEGY

Active testing model is an example of a sequential decision-making process and one way to formulate the *where to look next* problem (Geman and Jedynak, 1996). Active testing can be defined as a process in which an image is sequentially probed for information in order to determine efficiently the presence of one or more objects drawn from an object library.

The computational strategy of active testing is the inspiration for the road delineator to be presented. As a road manifests on medium- and high-resolution images as a smooth and elongated region, a piecewise rectangle modelling can be used. This means that the road is modelled locally by the semantic object rectangle, whose dimensions (width and length) are adaptable to the locally longest road straight segment. As the rectangle is a model for a variable straight segment of road and, as such, needs to locally adapt to the radiometric and geometric characteristics of the road, from now on it is denominated adaptive template. As will be shown in Section 2.1 and 2.2, the adaptive template is the base for the test (or exploratory action) to be accomplished to localise the longest road straight segment ahead the last extracted point of road centreline. The general computational strategy of active testing was also used by Geman and Jedynak (1996), who used it to extract roads from the low-resolution panchromatic SPOT satellite imagery with a ground resolution of ten meters. Although the major goal of this method is also to sequentially localise road segments, the test used is statistical, which is very different from our deterministic test based on the adaptive template. In the following, it will be presented the principle of the test based on the adaptive template.

2.1 Adaptive Template and Principle of Exploratory Action

As shown in figure 1, the adaptive template T is a m x n matrix representing an ideal road straight segment. In order to allow the template T to geometrically coincide with a local road segment, the template dimensions m and n needs to be recomputed (or readapted) whenever a new test is carried out for finding a new road segment. The dimensions m and n must be locally

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compatible to the longest local road straight segment. More details about the determination of the template dimensions are given later. In order to include radiometric information for the template, the gray levels of its n.m elements are resampled from the image data. In the figure 1, point P is the last extracted point of the road centreline and is at this point the template T is established. Thus, point P is the reference for the exploratory action, which is accomplished by rotating the template T at small steps by a predefined angle in both clockwise and anti-clockwise directions, having as origin the approximate road direction defined by the last extracted points. The goal of this exploratory action is to identify the longest road straight segment ahead point P.

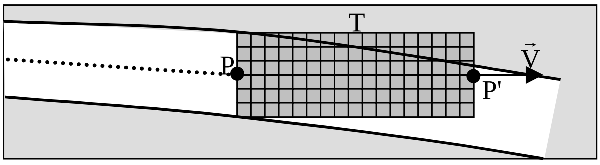


Figure 1. Definition of adaptive template T

The best matching between template T and road is identified by a similarity measure (M), which embodies following two photometric and geometric characteristics of object road: 1- roads are elongated and usually lighter than the background; e 2- within a short road segment grey levels do not change very much. The similarity measure is as follows,

$$M = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} T^2(x_i, y_j)}{\sum_{i=1}^{m}\sum_{j=1}^{n}[T(x_i, y_j) - T_M]^2} \qquad (1)$$

where $T(x_i, y_i)$ is a (m x n) matrix of resampled grey levels
T_M is the average grey level of template T

The best matching holds when M is maximum. The orientation of template T as conveyed by the best matching is the best local orientation of the road at P (figure 1). The new point P'(x',y') of road centreline (figure 1), which corresponds to the best matching between T and the road, is linearly extrapolated ahead by using the template length and best local road orientation at last extracted point P.

The exploratory action above described is repeated sequentially to allow the entire road centreline to be extracted. In order to compute template dimension m, we assume that road width w does not change too much. Thus, m can be defined as the next superior integer of a parameter m' satisfying w= r.m', being r the pre-defined template resolution.

2.2 Determination of the Template Length

The basic difficulty to determine the length of template is the lack of information of the road segment situated ahead the last extracted point. The exploratory action presented previously can be extended to allow the length of template, which is compatible to the longest road straight segment, to be determined. The principle of process to determine the best template length (n_{opt}) is shown in figure 2. In order to avoid the determination of template length over an unlimited interval, a minimum length (n_{min}) and a maximum length (n_{max}) are pre-established. The parameter n_{min} should be selected slightly greater than the road width to allow the method to be less sensitive to irregularities as, e.g., shadows cast over the road or a light blob on the road margin. The parameter n_{max} should be limited to avoid too large searching area.

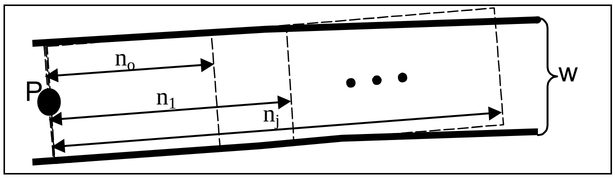


Figure 2. Principle to determine the best template length (n_{opt})

As shown in figure 2, the process of determining the best template length starts with the establishment of the template at point P, for which the dimensions are m= int(w/r) +1 and n_o= n_{min}. An exploratory action with this template is carried out and the best road direction (V_o) and the similarity parameter (M_o) are stored. The template is re-established at P with the same width (m) but with n_1= n_{min}+j.dt, being j= 1 and dt= 1 pixel. The exploratory action is also repeated and the new values for the best road direction (V_1) and the similarity measure (M_1) are computed and stored. This strategy is repeated until j reaches the limit given by equation 2.

$$j = \text{int}\left[\frac{n_{max} - n_{min}}{dt}\right] \qquad (2)$$

Plotting the similarity measures (M_o, M_1, ..., M_j) on a two-dimensional co-ordinate system, having the template lengths (n_o, n_1, ..., n_j) as x-axis, the shape of the two-dimensional curve obtained is similar to one shown in figure 3.

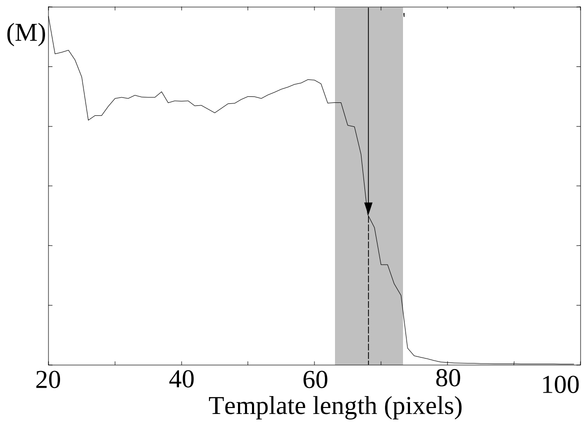
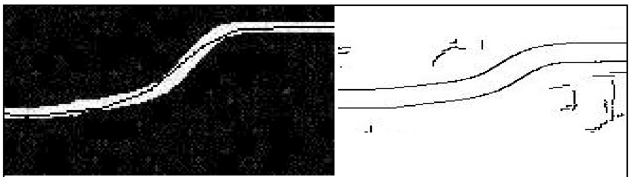


Figure 3. Curve of maximum of M

As shown in figure 3, the curve of maximum of M does not vary much for template lengths ranging from 20 pixels to 60 pixels but varies very sharply around template length of 70 pixels. The interval between 20 pixels and 60 pixels corresponds to the strong matching between the template and the road. Contrary to this, the matching between the road and the template becomes weak at the narrow interval around template length of 70 pixels. This means that the transition region highlighted in grey in figure 3 contains the best length for the template, which is about 70 pixels for the example of figure 3. Thus, the analysis of M maximum curve allows the best template length (n_{opt}) to be determined. As M maximum curve in transition area behaves as an one-dimensional step edge profile, an edge detection technique can be used to determine the value of n_{opt}.

3. POST-PROCESSING USING EDGE INFORMATION

The active testing-based delineator previously described has the robustness as an important characteristic. However, it does not generally allow an accurate road centreline determination to be obtained. As shown in figure 4(a), the extracted road from a noisy synthetic image does not coincide to the road centreline on most part of the road segment. Edge information (figure 4(b)), obtained in this case by Canny edge detector with gaussian scale factor $\sigma = 6$, can be used to correct the road extracted by active testing strategy. Right below is presented a strategy of using edge information to refine previously extracted road centreline.



(a) (b)

Figure 4. Illustrative example using a noisy synthetic image. (a) Typical result obtained from the application of active testing strategy. (b) Edges detected using Canny edge detector.

The most representative road edge pixels must be under two basic rules, i.e. anti-parallelism rule and perpendicularity rule. The former is based on the fact that two gradient vectors at two pixels situated on opposite road margins and belonged to the same road cross-section, are approximately anti-parallel, i.e., the angle between them is approximately 180^0. The latter is based on the fact that gradient vectors at road margin pixels are approximately perpendicular to the road centreline.

The refinement of the road centreline is based on an one-dimensional searching for road edge points along cross-section of the road centreline extracted previously by active testing strategy. Basically, for each pre-existing road centreline point is established a cross-section, along of which the one-dimensional searching is carried out to find road edge points on both sides of the pre-existing road centreline. Assuming that the pre-existing road centrelines are at least on the road surface, and also the road width (w) does not change much, any road edge point should be found at maximum distance of w from the pre-existing road centreline. In general, if a consistent road edge point is found on one margin at distance of d< w from the pre-existing road centreline, there is a great chance of finding the other road edge point on the opposite margin at distance of w-d from the pre-existing road centreline. Assuming now that for each margin there is only one consistent road edge point, or no one for e.g. not well-defined road edge, then the correction or the elimination of the pre-existing road centreline points is based on three possible cases:

1. **Two road edge points are found**: the correct position of road centreline point is computed as the middle point of both road edge points. These two points are also useful for updating the mean road width;
2. **One road edge point is found**: the correct position of road centreline point is computed in function of the detected road edge point, the mean road width, and the orientation of current road cross-section; and
3. **No road edge point is found**: the pre-existing road centreline point is eliminated.

In order to identify what is the case for a given road cross-section, it is need to detect the most representative road edge pixels on both sides of pre-existing road centreline. Firstly, we use Canny edge detection method (Canny, 1986; Jain et al., 1995) for detection and thinning of all image edges. Then, the resulting edge image and gradient information are used to detect only road edge pixels by using basically the anti-parallelism and perpendicularity rules.

This strategy has a satisfactory performance whenever the direction of pre-existing road centreline does not deviate too much from the road edge direction. This is because the one-dimensional searching windows are established along cross-sections of the pre-existing road centreline and, as such, the corresponding road centreline point computed from road edge points can be systematically displaced from the correct ones. An iterative process is used to avoid this problem, in which the above strategy is iterated until no significant correction of computed road centreline points are verified at two successive iteration.

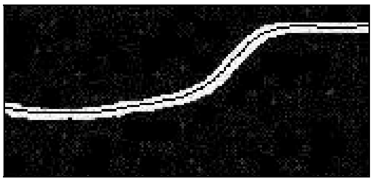


Figure 5. Result of correction of pre-existing road centreline using edge information

Figure 5 shows the result obtained using the strategy described above, whose input data are the pre-existing road centreline (figure 4(a)), the edge image (figure 4(b)), and gradient data. This simple illustrative example shows that the position of pre-existing road centreline is significantly improved with the edge information.

4. EXPERIMENTAL RESULTS

The approach previously described was implemented on a PC environment using Borland C++ computer language. Until now, the software does not have any graphic interface to assist the operator in supplying the necessary information (e.g., seed points) to initialise or re-initialise the extraction process. The seed points are collected by an available commercial software and supplied, together with other information (e.g., parameters for initialising the Canny edge detection routine), via ASCII files to the extraction system. In order to experimentally

evaluate the potential of the method, one experiment with medium-resolution image was carried out. The road on the test images is 5-7 pixel width. Below we present and discuss the results.
Figure 6 is medium-resolution image (671 x 379 pixels). In this image is shown a forest road with good contrast but with great amount of geometrical irregularities, as e.g. very irregular widths, road regions partially or totally occluded by tree clusters, and one large light blob on the road margin. The two seed points used to initialise the active testing delineator are overlaid as white dots on the input image. In order to facilitate the visual analysis, the results obtained in both steps of the method are also overlaid on the input image, but now as black lines. As is shown in figure 6(a), the road centreline extracted by the active testing strategy is very close to correct road centreline. The main reason for this good performance is the good road contrast in relation to the background. Notice that the road parts partially and totally obstructed by tree clusters do not influence significantly the road delineation. However, the result obtained on the road part disturbed by the light blob is a little bit deficient, as the extracted road centreline developed a corner at that place. As is shown in figure 6(b), a good quality result is obtained after three iterations with the strategy using edge information. Although the corner generated in the first step is removed, another very small corners are generated, which are expected due to the road edge irregularities. These road centreline irregularities can be removed using a post-processing procedure independently of the road extraction procedure. The time expended to process the two steps of the method, using an 850 MHZ Pentium III, was approximately 4 seconds.

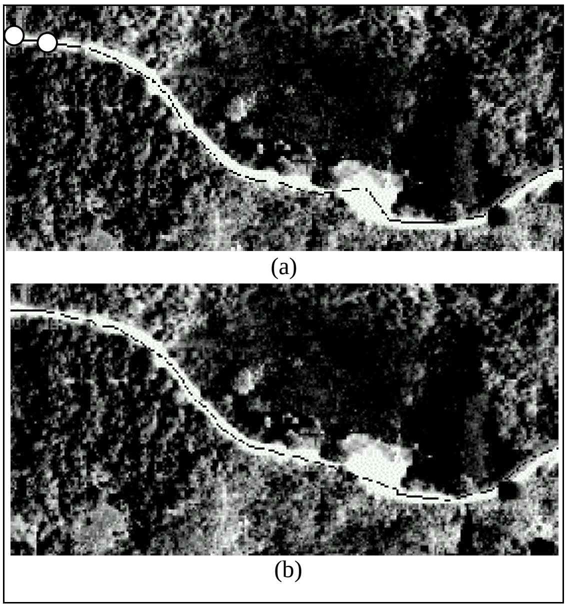


Figure 6. Experiment with medium-resolution image. (a) Results obtained with active testing strategy. (b) Results obtained using edge information.

In order to access the accuracy of the proposed method road centreline were manually extracted and numerically compared to corresponding one extracted by the road extraction algorithm. The node positions of road centreline were determined to be about 1 pixel from the manually extracted road centreline.

5. CONCLUSIONS

In this paper was presented a semi-automated method for extraction of road segments from medium- and high-resolution images. The preliminary evaluation of the method using one medium-resolution test image showed that it seemed to be very promising. The step based on active testing strategy did not generally extract accurate road centreline. The test image presented irregularities related to the edges (e.g., absence or poor definition of one or both road edges), to the road width, and to the occlusions resulted mainly from trees. These irregularities did not cause the interruption of the active testing process. Therefore, the active testing strategy proved to be robust and accurate to initialise next step properly. This last step (i.e., the edge-based strategy) provided results that are close to ones that would be extract manually. Even in the cases in which the approximate road centreline extracted by the active testing strategy was not so good, as e.g. a road segment with sharp corner (figure 6(a)), the result obtained by the iterative scheme using edge information was satisfactory.

6. ACKNOWLEDGEMENTS

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