SEMI AUTOMATIC TRACKING OF ROAD CENTERLINES FROM HIGH RESOLUTION REMOTE SENSING DATA

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ABSTRACT: Extraction of curvilinear features such as roads, railroads, and rivers has been one of popular research topics in computer vision, photogrammetry, remote sensing and GIS communities. Automation of such extraction has been key research issue, although full and reliable automation is yet to be achieved. This paper describes an algorithm for tracking road centers. We intend to use the algorithm in semi-automatic road extraction from 1m high-resolution satellite images. Until now, road extraction based on perceptual grouping, snakes, energy minimization or template matching with global enforcements has been proposed. In this paper, we will use least squares template matching without global enforcements for road center tracking and show that it works. In our algorithm, once an input point on a road centerline is provided from a user, a road template is defined on that point and subsequent road center points are extracted by template matching. A 1m resolution IKONOS image over Seoul area was used for test. The algorithm could extract road centerlines in any orientation with a few user input points. To extract major 29 road segments from a IKONOS sub-scene it took about a few minutes including the user interaction and system computation time of 21 seconds. The contribution of this paper is that we proved template matching could offer wider applicability in feature extraction than energy minimization approaches and that we designed a new template matching scheme that worked for feature extraction without global enforcements.

1. INTRODUCTION

Extraction of curvilinear features such as roads, railroads, and rivers has been one of popular research topics in computer vision, photogrammetry, remote sensing and GIS communities. Delineation of road centerlines from remote sensing data is gaining research interests in particular with the availability of spaceborne high resolution images. Various methods proposed for this theme include perceptual grouping, (Trinder and Wang, 1998; Katartzis *et al.*, 2001), scale-space approaches (Mayer and Steger, 1998), neural network and classification (Doucette *et al.*, 2001), "snakes" or energy minimization (Gruen and Li, 1997), and template matching (Vosselman and Knecht, 1995; Gruen *at al.*, 1995; Hu *et al.*, 2000). Although many authors have focused on the development of fully automated algorithms, it seems that semi-automated algorithms such as "snakes" and template matching seemed to gain acknowledgement.

"Snakes" or energy minimization approaches work by defining appropriate energy functions based on geometric and radiometric assumptions of features of interest. From an initial estimate of a feature, they refine the solution to minimize the energy. This approach may work for some applications but may be troublesome in applications where it is difficult to define appropriate energy functions. Template matching may be used in such applications instead. Template matching works by defining a template from one point on the feature of interest and find the rest of the feature by matching. In order to apply template matching, the features of interest must possess similar brightness patterns. Given this condition, the key issue of template matching is how to guide matching to extract meaningful features of interest successfully. Gruen *et al.* (1995) used additional geometric constraints (or global enforcements) and used them to determine correspondence together with correlation measure (Gruen, 1985). Hu *et al.* (2000) used neural network to optimize template matching results.

In this paper we introduce a new semi-automatic road extraction algorithm based on template matching. Our work was motivated by the previous work of Gruen *et al.* (1995) but our algorithm differs from the previous work in the following ways: we focused on tracking road centerlines from high resolution images while the previous work focused on tracking roads from mid or low resolution images; and we eliminated the need to have additional constraints for guiding template matching by designing a new least squares correlation matching scheme.

We designed a new template matching algorithm based on the following considerations. In images at 1m resolution, road centerlines are appeared as curvilinear features and have distinctive brightness patterns compared to their surroundings. And hence, we could apply template matching along the road centerlines. Also we assumed that although there are geometric distortions we could model the geometric transformation between one point and the other on a road centerline as similarity transformation. Hence, if we draw a rectangular window centered on a point of a road centerline, we can define the corresponding window at another point of a road centerline by translating and rotating the rectangle. The mathematical expression of this algorithm is given in the next section.

2. ROAD EXTRACTION ALGORITHM BASED ON TEMPLATE MATCHING

We express the relationship between a template and a target window along a road centerline as below

$$x_{target} = x_{template} \cos q + y_{template} \sin q + s_1 - s \sin q_{template} \quad (1)$$

$$y_{target} = -x_{template} \sin q + y_{template} \cos q + s_2 + s \cos q_{template} \quad (2)$$

where $q_{template}$ is the road orientation at the template point and s the shift distance along perpendicular to $q_{template}$. Here, s_1 and s_2 are set to indicate the distance in x and y direction, respectively, between the template and initial guess. They remain constant through iteration. Least squares correlation matching assuming this similarity transformation can be achieved using the following matrix equation.

$$\mathbf{l} = \mathbf{A}\mathbf{x}$$

$$\mathbf{l} = \left\{ f\left(x_{template}, y_{template}\right) - g\left(x_{target}, y_{target}\right) \right\}$$

$$\mathbf{x}^T = \begin{bmatrix} \Delta q & \Delta s & r_s \end{bmatrix}$$

$$\mathbf{A} = \left\{ -(d_x \sin q + d_y \cos q) x_{template} + (d_x \cos q - d_y \sin q) y_{template} \quad -d_x \sin q_{template} + d_y \cos q_{template} \quad 1 \right\}$$

The procedure of the overall road extraction scheme is given in figure 1. A user, first of all, will identify one point on a road centerline. Then a template window will be defined centered on the point and the orientation of the template (or the road centerline) will be estimated. The orientation of the road is important in our algorithm since it defines the direction of template matching. One of the major differences between our algorithm and previous work on template matching (Gruen *et al.*, 1995; Vosselman and Knecht, 1995; Ho *et al.*, 2000) is that others require additional constraints to guide matching for meaningful feature extraction whereas we guide matching only by the orientation information of match windows. The orientation on the initial road template can be estimated either by applying automatic line extraction method proposed by Burns et al. (1986) or by selecting one more user input points on the direction of road. The second method increases the degree of human interaction significantly but has the advantage that in this way the direction as well as the start and end of road extraction can be controlled.

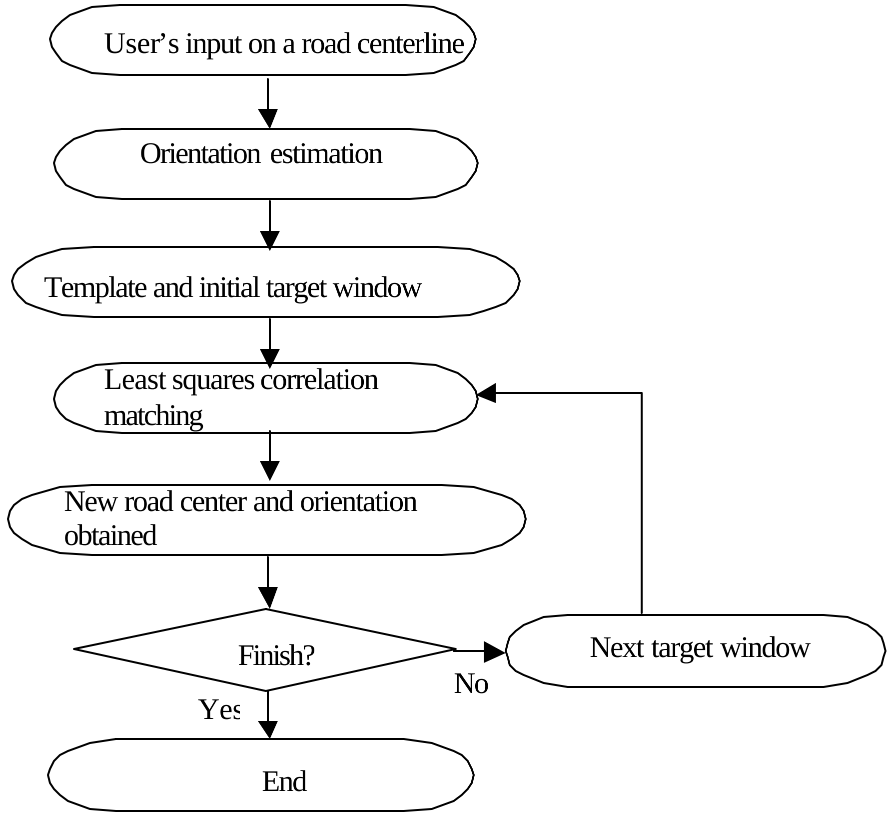

Figure 1. The procedure of semi-automatic road extraction

After estimating the orientation a template and initial target windows are generated. A template window is defined whose center is at the user input point and whose orientation is aligned to the road orientation. An initial target window is generated by shifting the template window to the direction of road. Least squares correlation matching is then applied. The position and orientation of target window is updated iteratively. Once matching is completed the location of a new road centerline and its orientation are achieved. This information is used in turn as a new template point and orientation and the template matching process repeats.

The results of our semi-automatic road extraction comprises of several road segments whose length may vary. In order to describe complete road centerlines, post processing may be required. In the current implementation, road segments can be combined with each other, deleted or modified.

3. RESULTS

The algorithm was tested with 1m resolution IKONOS image over Seoul area. Figure 2 shows the test image and the results of road extraction. Among various types of roads within the image, all major roads whose centerlines were visible were successfully extraction. In this example, an operator provided a series of input points along one road centerline. The orientation of template point is defined from the adjacent two input points and template matching applied only between them. The road extraction was tested several times by different operators. On average 29 segments were required to track the whole roads as shown in the figure, where three to five user input points were given for one segment. Computation time taken for template matching was 21.2 seconds on average. An experienced user could finish the task of semi-automatic road extraction within a few minutes.

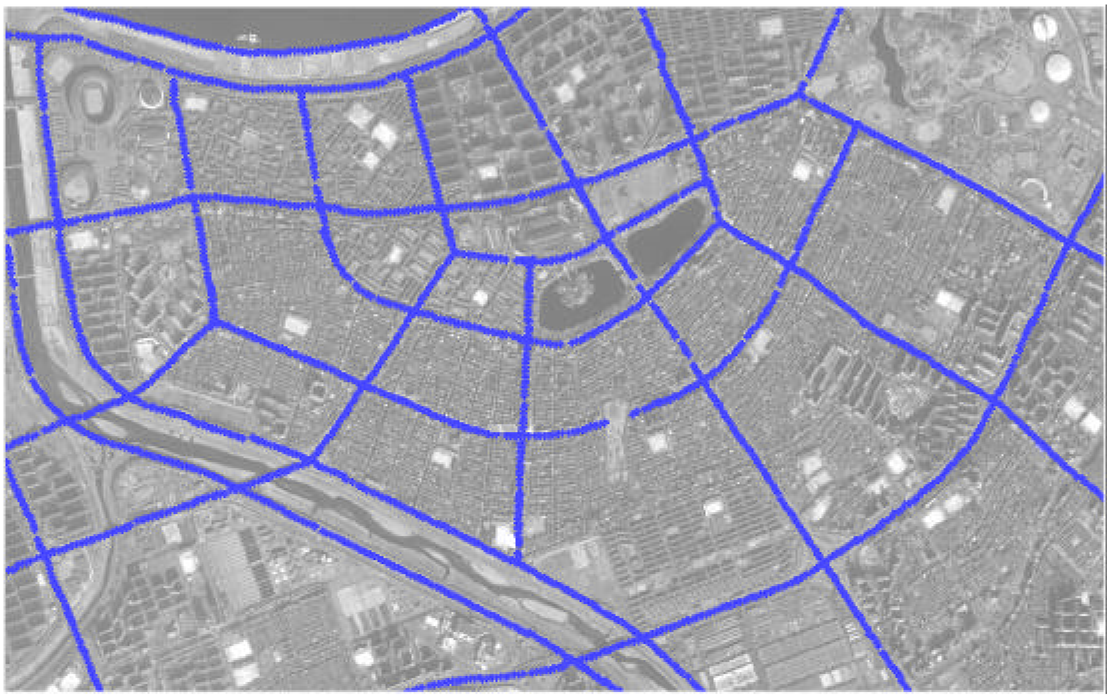

Figure 2. The test image over Seoul and the results of road extraction

There are still many roads remained not extracted. In most cases, they were small roads without centerlines and parking lots within apartment or industrial complexes. If required, most of them can be extracted by simply measuring two end points and extracting the straightline between the end points.

Figure 3 shows very interesting results of our algorithm. It tracks the ridge of a stadium. In this example, a user provided one point on the inner ridge of the stadium and the orientation of the ridge at that point was estimated by line extraction. Our algorithm successfully tracked the rest of points along the edge of the stadium. Since we are using template matching scheme, our algorithm can track any point whose brightness patterns are similar enough. This flexibility, however, can sometimes be a drawback. A user needs to be more careful to select valid input point on a road centerline in order to extract precise road centerlines. This property may be eased if we refine user input to be projected onto a nearby line segment automatically.

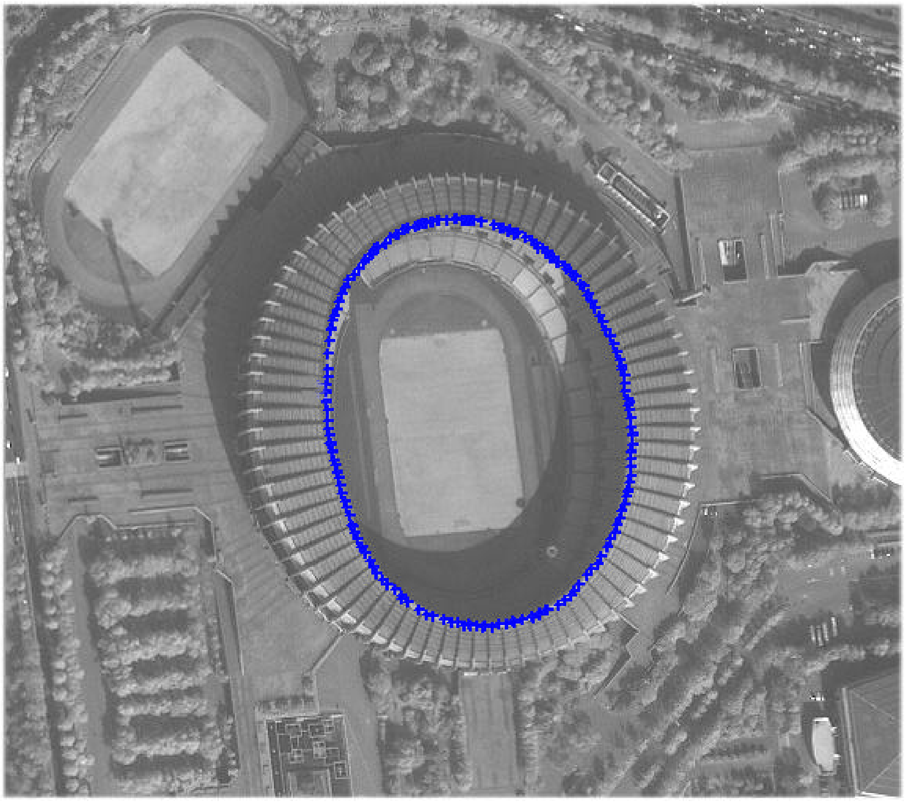

Figure 3. The result of template matching over the ridge of a stadium

4. CONCLUSIONS

In this paper, we proposed a new semi-automatic road extraction algorithm. From the high-resolution satellite image, road centerlines are extracted by using template matching based on least squares correlation matching. The experiments with an IKONOS image showed that the most of road centerlines of highways and major streets were extracted effectively given a few user input points.

The contribution of this paper is that we proved template matching could offer wider applicability in feature extraction than energy minimization approaches and that we designed a new template matching scheme that worked for feature extraction without global enforcements.

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