SEMI-AUTOMATIC EXTRACTION OF RIBBON ROADS FORM HIGH RESOLUTION REMOTELY SENSED IMAGERY BY COOPERATION BETWEEN ANGULAR TEXTURE SIGNATURE AND TEMPLATE MATCHING

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ABSTRACT:

Road tracking is a promising technique to increase the efficiency of road mapping. In this paper an improved road tracker, based on cooperation between angular texture signature and template matching, is presented. Our tracker uses parabola to model the road trajectory and to predict the position of next road centreline point. It employs angular texture signature to get the exact moving direction of current road centreline point, and moves forward one predefined step along the direction to reach a new position, and then uses curvature change to verify the new added road point whether right enough. We also build compactness of angular texture signature polygon to check whether the angular texture signature is suitable to be used to go on tracking. When angular texture signature fails, least squares template matching is then employed instead. Cooperation between angular texture signature and template matching can reliably extract continuous and homogenous ribbon roads on high resolution remotely sensed imagery.

1. INTRODUCTION

Extraction of road from digital aerial/satellite imagery is not only scenically challenging but also of major importance for spatial data acquisition and update of geodatabases. Traditional manual plotting is time consuming and expensive, so automatic acquisition and update of road data is greatly needed. In (Bajcsy and Tavakoli, 1976; Wang and Newkirkr, 1988; Trinder and Wang, 1997; Long and Zhao, 2005; Haverkamp, 2002; Hinz and Baumgarter, 2003; Zhang and Couluigner, 2006; Barzohar and Cooper, 1996; Gardner and Roberts, 2001; Baatz and Schape, 2004), various fully automatic approaches are proposed. But the road characteristics vary considerably with ground resolution, road type, density of surrounding objects, and light conditions and so on, adding that the limits of state of the art on computer vision and photogrametry, the desired fully automation could not be achieved by now, however, semi-automatic approach that retains the human operator in the loop where computer are used to assist human performing is considered to be a good compromise between the fast computing speed of a computer and the efficient interpretation skills of an operator. And quite a lot of promising approaches for semi-automatic road extraction have been proposed in the last two decades. Quam (1978) tracked road by road surface model and profile model; Nevatia and Babu (1980) proposed edge-based technique; Mckeown and Denlinger (1988) combined edge-based and profile correlation based approach; Vosselman and de Knecht (1995), Baumgartner (2002) and Zhou (2006) used least square profile matching; Park and Kim (2001), Hu, Zhang and Zhang (2000) employed template matching; Grun and Li (1995), Merlet and Zerubia (1996) connected road seeds by dynamic programming; Grun and Li (1997) used snakes to optimize the path of road seed points; Vandana and ChandaraKanth and Ramachandran (2002) employs minimum cost to follow a path; Baltsavias (2004) revised road map based on existing geodata and knowledge. But a standard cliché of road extraction is that every algorithm has its limits, so we believe that a number of techniques developed for different classes of road will lead to a many-branched solution for road extraction that will be effective for a wide range of road types. Improved angular texture signature is proposed and cooperation between angular texture signature and template matching is employed to semi-automatically extract road network in this paper.

Road characteristics and the principles of the proposed algorithm are described in Sect. 2. In Sect. 3 we introduce the process of our tracker. Section 4 compares our tracker with classic algorithms. Section 5 evaluates the tracker by a case study. Section 6 summarizes the results of our study and makes a conclusion.

2. METHOD

2.1 Road characteristics

Road characteristics can be classified in five groups: geometrical, photometric, topological, functional and contextual characteristics (Vosselman and de Knecht, 1995; Grun and Li, 1997; Zhou, 2006) on high-resolution imagery. Details of these characteristics are:

1) Geometry
   a) Roads are elongated ribbons rather than linear features;
   b) A road segment has a maximum curvature;

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c) A road segment has a constant width.

2) Radiometry

d) The road surface usually is smooth and homogeneous;

e) The road has a good contrast with its adjacent areas.

3) Topology

f) The road will continue and do not stop without a reason;

g) The roads intersect and form a network.

4) Function

h) The roads connect human settlements.

5) Context

i) Overpasses, higher roads, adjacent buildings and tress may cast a shadow;

j) Roads may be occluded by vehicles and other obstacles.

The operator use the above characters and prior knowledge to detect and identify a road segment, and the proposed tracker works based on a), b), c), d), e) properties

2.2 Principles of angular texture signature

A texture measure is described in (Haverkamp, 2002) and defined and extended by us as follows. At each pixel p of a grey image, angular texture signature (ATS) $T(\alpha, w, h, p)$ is defined as the mean, standard deviation, variance or entropy for a rectangular set of pixels of width w and height h around the potential road pixel p whose principal axis lies at an angle of α from the potential road direction. This measure is computed for a set of angles $\alpha_0, \ldots, \alpha_n$ at pixel p .At the point p , the ATS is defined as the set of values $\{T(\alpha_0, w, h, p), T(\alpha_1, w, h, p), \ldots, T(\alpha_n, w, h, p)\}$. The graph and values of an ATS for a single point p are shown in Fig. 1. The local limits on this graph correspond to the most likely directions of the road at point p (e.g. directions 3, 10, 20, 29). At each pixel p , the number k and location of the strong local limits are computed from the ATS. For example, the signature shown in Fig. 1(a) has 4 limits that are significant. We refer to the number k of limit as the degree of the pixel. The texture measures that are used in road detection are: the degree of the pixel and the direction of the limit. In our approach, on the assumption that the roads have the above a), b), c), d), e) properties, a rectangular template is extended from and rotated 180 deg from the perpendicular of the potential road direction about each road pixel. At discrete intervals about the pixel, the ATS is calculated; and the direction of the limit is regarded as the road direction. If the ATS takes the variance or entropy as measure, the direction of local minimum is taken; while if the ATS takes the mean as measure, the direction of local minimum is takes for bright roads and the direction of local maximum is taken for darker road as shown in Fig. 2. Once the road direction is given, move on one step along the direction and iterate the above process until the tracker fails or reaches to another tracked road trajectory or reaches to the boundary of the image.

2.3 Road trajectory model

Road trajectory can be modelled by B-splines (Trinder and Li, 1997), straight line (Haverkamp, 2002), Kalman filter (Vosselman and de Knecht, 1995), extended Kalman filter (Zhou, 2006), particle filter (Zhou, 2006), and parabola (Mckeown and Denlinger, 1988).

The parabola in the $x \perp y$ plane can have arbitrary orientation, having an equation of the form:

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0 \qquad (1)$$

where x and y are coordinates of point on the parabola, A, B, C, D, E, F are parameters.

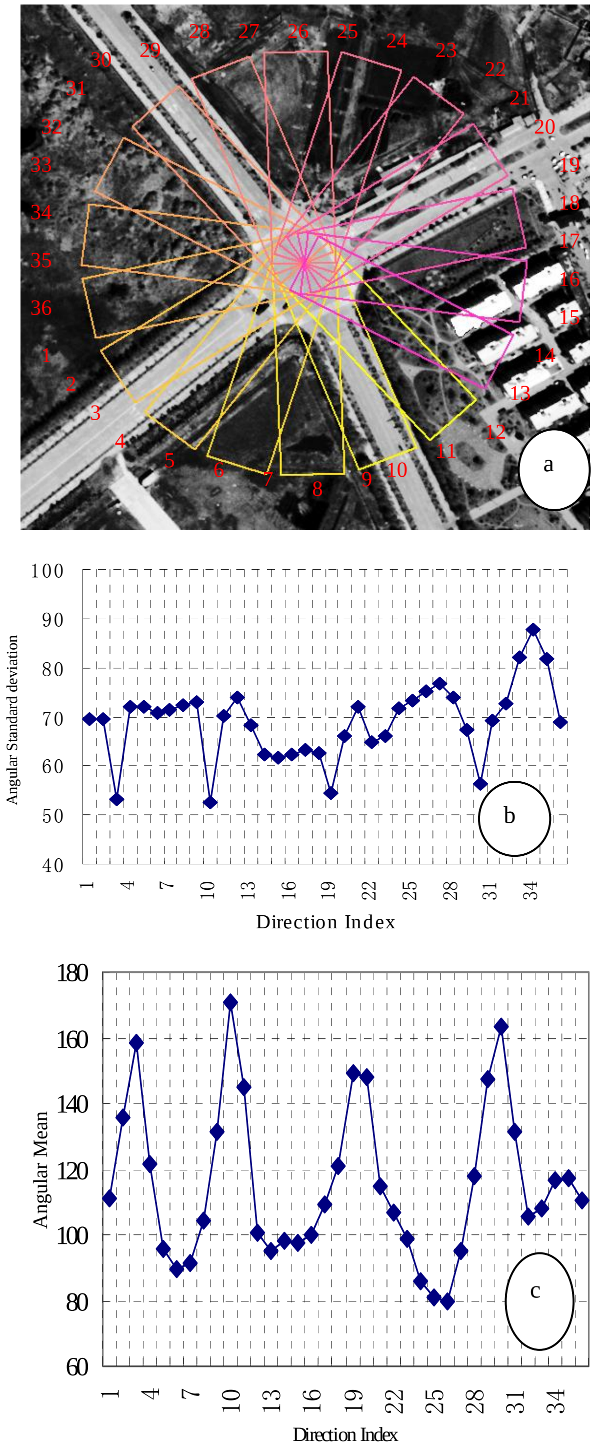

Fig.1 Angular texture signature (a) The effect of rotating templates in 36 discrete angles (the rectangles whose indexes are odd is invisible for convenience) (b) The standard deviations of 36 templates (c) The means of 36 templates

We don't use this equation since the parametric form is more convenient for our purpose. We represent the road path parametrically as two separate functions $x(l)$ and $y(l)$ where l is the total length in steps that we have traversed along the road's path. We use multiple regression with l^2 and l as the independent variables to fit parabolas to $x(l)$ and $y(l)$, getting approximate functions:

$$\begin{aligned} X(l) &= a_1 l^2 + b_1 l + c_1 \\ Y(l) &= a_2 l^2 + b_2 l + c_2 \end{aligned} \quad (2)$$

where $X(l)$ and $Y(l)$ are the road centreline points x coordinates and y coordinates, $a_1, b_1, c_1, a_2, b_2, c_2$ are the parameters.

To get the most possible potential direction of the road, we resort to compute $X(l+1)$ and $Y(l+1)$, that is the most possible location of the next road centreline point.
Given that the road segment has a maximum curvature, then the change of the curvature of two adjacent road points must be less than a predefined threshold T. The curvature K at some point on the parabola can be computed as follows:

$$K = \frac{2|b_1c_2 - c_1b_2|}{[4(c_1+c_2)^2 l^2 + 4(c_1b_1 + c_2b_2)l + b_1^{\ 2} + b_2^{\ 2}]^{3/2}} \quad (3)$$

where $a_1, b_1, c_1, a_2, b_2, c_2$ are the same as in Eq. (2).

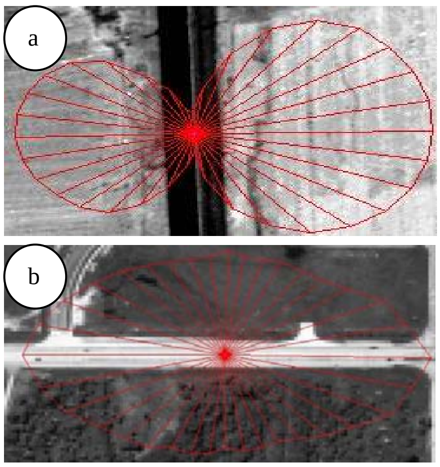

Fig.2 The wind rose chart of Angular Texture Signature (a) The mean ATS of a darker road (b) The mean ATS of a brighter road

2.4 Compactness of ATS

When we take a closer look at the ATS rotating a full 360 deg of each pixel, we can find some interesting links between the shape of the ATS polygon and corresponding pixel types. To form the ATS polygon, instead of plotting the ATS values for each direction along a horizontal line, we plot the ATS values around the pixel under consideration with corresponding direction and link the last point to the first point. The resulting polygon is called the ATS polygon. Fig. 2 shows the calculated ATS for some interesting pixels with the ATS polygons shown in red. If the road has a good contrast with its surrounding objects, the polygon looks like an ellipse or ∞-Shape. The compactness of ATS is defined as the compactness of the ATS polygon using Eq. (4). We must note that the ATS polygon in our tracker is just half of the above illustrated polygon because we just rotate the rectangular template 180 deg, and our ATS polygon is form by plotting the ATS values around the pixel under consideration with corresponding direction and link the last point and the first point to the current pixel. The compactness tells us whether the ATS polygon looks like a circle. A circle-like ATS polygon usually means that the tracker is no longer fit to be used to follow road centerline point, and it needs manual plotting.

$$\text{ATS}_{\text{compactness}} = \frac{2 \cdot \pi \cdot A}{P^2} \quad (4)$$

where A and P are the area and perimeter of the ATS polygon, respectively. Note that P doesn't include the distance between the first point and the current pixel and the distance between the last point and the current pixel.

2.5 Least square template matching

Our least squares template matching is as the same as Park and Kim' one (2001).

3. THE PROCESS OF OUR TRACKER

Semi-automatic road extraction here is undertaken as follows.

3.1 Pre-process the input image

If the original image doesn't have a good contrast between road and other features, it needs stretching. Then the image is convolved with a Gaussian filter to smooth the image and reduce the high-frequency noise.

$$G = \exp(-\frac{x^2 + y^2}{2\sigma^2}) \quad (5)$$

where $\sigma = \sqrt{2}$ pixels.

3.2 The operator detects a road segment

A human operator has to identify a short part of a road axis; this road part serves as initialization for an automatic tracker. The tracker need a starting point on the road centreline and a second point to define the direction of the road and a third point to define the width w of the road. Then the road tracker move forward at least 5 steps along the initial direction, then the road trajectory model can be built by Eq. (2). Predict the next road position and get the most possible potential road direction.

3.3 Compute ATS

From the last road centreline point in the trajectory, a rectangular template is formed with width w and height $2*w$, and rotate 180 deg from the perpendicular of the predicted direction. At discrete intervals about the pixel, the angular texture signature is calculated. Selecting which texture signature as the measure of ATS, it should judge by the road conditions. After a lot of experiment, we conclude that, taking variance, strand deviation or entropy as the measure of ATS if the road has salient characteristic d) while taking mean as the measure of ATS if the road has obvious characteristic e).

3.4 Compute $ATS_{compactness}$ and move forward one step ahead

Calculate the $ATS_{compactness}$ by Eq. (4). If the value is larger than predefined threshold T_1, it tells us that the ATS is not fit any more to track road, and it needs least squares template matching instead. Otherwise the direction of the limit is regarded as the road direction, and moves the road trajectory one step.

3.5 Compute the change of the curvature

Calculate the curvature of the new added road centreline by Eq. (5), compare it with the curvature of last point, if the difference is larger than predefined threshold T_2, delete the new point from the road trajectory, and resort to manually plot. Otherwise, predict the next road position by parabola equation and iterate from 3.3 if the trajectory doesn't reach to another trajectory or the boundary of the image. Once the user accomplishes one road segment or the tracker reaches to one tracked road or the boundary of image, initializes another road segment and restart from 3.2 again until all roads are tracked.

From the operator point of view, the procedure is as follows: the operator has to initialize the tracker by three input points to indicate the starting, the moving direction and the width of the road segment, and then the tracker is triggered. Whenever the internal evaluation of the tracking tool indicates that the tracker might lost the road axis or be no longer fit, it demands for interaction of the operator. Then the operator has to confirm the tracker or the user must edit the extracted road and put the tracker back on the road.

4. COMPARISION OF FOUR TRACKERS

To verify our algorithm, we make a comparison between least square template matching, least square profile matching, snakes and our tracker on a same Quickbird image of Huai'rou County in Beijing, China, whose size is 355 by 1066 pixels. On this image, there is a brighter centreline on the homogenous darker road surface with a brighter background. The results are shown in Fig. 3. All trackers extract the road centreline with different precision in red colour. For profile matching, the front part of the path is quite good but the last part of the extracted road trajectory has a larger deviation due to the larger curving of the road. For template matching, the extracted road trajectory is good but with some larger deviate points along the trajectory. For snakes, if there is only two seed points on centreline, the extracted road trajectory is quite wrong, as shown in Fig. 3(c), the up line; but if there is 5 road seed points, the result are quite good, as shown in Fig. 3(c), the down line. For ATS taking variance as measure, there is some acceptable deviation in the middle part of the road. For ATS taking mean as measure, the extracted road trajectory is very good. We also record the time needed by each tracker. Profile matching is so fast that it finishes immediately after initialization. The snakes is slower than profile matching. The template matching is slower than snakes but faster than ATS. We can get the conclusion that our proposed algorithm is more robust than other trackers.

5. EXPERIAMENT AND EVALUATION

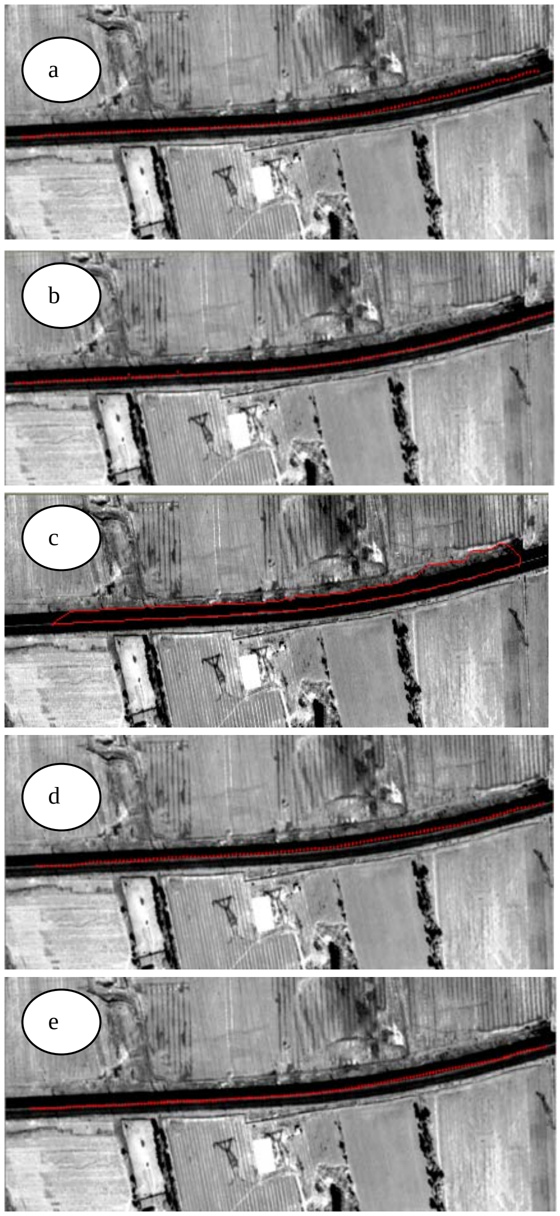

Fig. 3 Comparison of algorithms (a)The result of profile matching (b) The result of template matching (c) The result of snakes (d) The result of angular texture signature tale standard deviation as measure (e) The result of angular texture signature take mean as measure

The algorithm proposed here was tested by one Quickbird image over Hefei City, An'hui Province, China. The image with 2181 by 1998 pixels contains many different road types such as straight roads, curves, and crossings at different orientations. And for each segment, the surface material is same, but there is sudden change in radiometry, as shown in Fig. 4. The roads have different disturbing objects such as shadows of trees and occlusions by vehicles, but the shadow and occlusion is not serious. In the procedure of tracking, there are 8 times the tracker deviating the path, and then the thread is ceased as soon as possible by the operator. There are 6 times prompts notifying the user that the tracker is no longer suitable and it needs manual plotting. And there are only 76 manual input points, and the whole process takes 543 seconds. But if the operator want manually plot all path point with the same precision as the tracker, it needs 1108 inputs and it takes 776 seconds. In general, the quality of the result 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. We also test our tracker on many other grey scale images with different resolution varied from 0.2 to 2.5 m, and the results are similar in manual input saving about 90% and time saving about 30%.

The result shows that our tracker is quite robust when the photometric property of same road segment changes suddenly, and when the tracker reaches to the junctions and it will go on without stop. And the tracker can detect the road centreline of the roads in any orientation with moderate curvature accurately, and also works successfully for roads have some obstacles caused by shadow and occlusion.

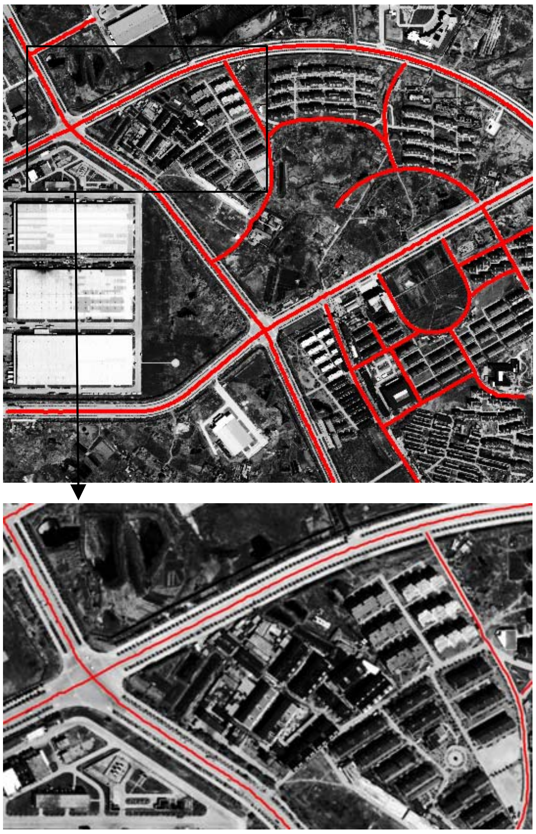

Fig. 4 Semi-automatic extracted road network on Quickbird image (a) Overview (b) Local result.

6. CONCLUSIONS

The proposed tracker based on ATS is very robust, because it makes best use of the road characteristics on high-resolution imagery. Our algorithm employ parabola equation to fit the trajectory of the road and to predict the road position and moving direction and to judge whether the new added road point is right by check the curvature change, it also utilize compactness coefficient to evaluate the aptness of itself to go on tracking, so the algorithm has some ability of higher-level reasoning. The current limitations are that the algorithm may not work on the road cast by much shadow and occlusion in complex scenes, it can't judge the validity of input seeds, it can only track long ribbon roads on grey scale imagery, and it need more computing times. These limitations are currently being examined now. The main contribution of this paper is that it employs angular texture signature semi-automatically extract road with precise results.

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