VECTORIZATION OF LINEAR FEATURES IN SCANNED TOPOGRAPHIC MAPS USING ADAPTIVE IMAGE SEGMENTATION AND SEQUENTIAL LINE TRACKING

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ABSTRACT:

Vectorization of cartographic features is a difficult task in geographic information acquisition from topographic maps. This paper presents a semi-automatic approach to linear feature vectorization directly in original scanned colour topographic maps without layer separation. In the approach, a sliding window is added on a user-given linear feature, and the current line in the window is segmented adaptively by using colour space conversion, k-means clustering and directional region growing. A thinning operation is then performed in the window and the line is tracked from the centre to the edge. By moving the window continuously along the line, vectorization is carried out by iterative operations of image segmentation, thinning and line tracking. Experimental results show that linear features in colour topographic maps can be vectorized rapidly and accurately, especially in those maps with forest tints and relief shadings.

1. INTRODUCTION

Map digitization is one of the most important means of geographic data acquisition for Geographic Information System (GIS) applications. In the past decades, map digitization has undergone the stage of manual tracking on digitizing tablets and the stage of heads-up screen digitizing. Currently, human-machine interactive digitization based on image processing and pattern recognition techniques has been more and more used.

Many commercial systems such as VPStudio, RxAutoImage, R2V and MapGIS are available for map digitization. Topographic maps are vectorized from raster images into vector data by raster-to-vector conversion. For black-and-white line drawings with high quality, automatic vectorization can be implemented by using line tracking method. However, for colour topographic maps, where cartographic features with different colours overlap and intersect one another, automatic vectorization is still a challenging task.

The existing techniques of colour map vectorization can be grouped into two main categories: colour segmentation based and original map based. The colour segmentation based method first split the colour map image into several layers with predefined map colours, and then vectorize cartographic features in the separated binary layers interactively or automatically. This kind of method can significantly reduce the complexity of cartographic features, and therefore make map vectorization relatively easy. Here, colour segmentation is a fundamental step. The precision and speed of map vectorization rely on the quality of segmented images. Many algorithms for colour segmentation including statistic pattern classification (Feng et al., 1996; Su et al., 1999), neural network (Lin et al., 1994; Guo et al., 1998), fuzzy clustering (Zheng et al., 2003), and others have been developed. Nevertheless, these algorithms are far from being satisfactory. Due to the influence of original paper map's quality and the scanner's performance, colours in a scanned map image are not the same as that in the original map. Large numbers of scattered colours and noises exist in the image, especially for the map with forest tints and relief shadings. So it is difficult to segment the colour map image into perfect colour layers with high qualities. Noises, gaps and adhesions appear everywhere in the separated layers, particularly in the contour line layer. Although some algorithms for removing noises and connecting broken lines have been developed (Cheng et al., 2003; Zeng et al., 2004), a great deal of human editing is still inevitable to acquire high quality image for automatic vectorization.

Another way to vectorize linear features is based on original scanned colour maps. In this method, a linear feature is tracked starting from a user-specified point, and some kinds of flexible user interventions are allowed in case where automatic tracking fails. This approach utilizes the strategy of human-machine cooperation, makes the line tracking process under human control, and provides the ability to correct data immediately if required. Therefore, it is more practical for colour map vectorization, and can be used as a complimentary of the former method. It should be a preferred one for the map image with poor quality. Unfortunately, to the best of our knowledge, very few research works have been done on such vectorization method (Wu et al., 1998; Huang et al., 2005).

MapGIS is one of the most powerful GIS software systems produced by Zondy Cyber Group Co., LTD, which provides the way of interactive line tracking in original colour map images. In the process of line tracking, the minimum colour distance rule is adopted to determine the next tracking point. From the point of view of applications, this method has two main disadvantages in performance:

(1) The line tracking process depends greatly on the user-specified starting point. The user needs to magnify the image and select the midpoint of a line exactly as the starting point. If the selected point has a little deviation, the following line tracking cannot be ensured to be along the centreline.

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(2) Automatic line tracking often fails when meeting other cartographic features with similar colour. Linear features can hardly be tracked in those maps with forest tints and relief shadings.

In order to overcome the above shortcomings, this paper presents a new technique for linear feature vectorization directly in colour map images. It is accomplished by using adaptive image segmentation and sequential line tracking based on sliding window.

2. THE ANALYSIS OF COLOR TOPOGRAPHIC MAP IMAGES

Topographic maps typically use only a few distinct colours to represent different cartographic feature layers, for example, black cultural features, brown geomorphologic features, blue water areas, green vegetation, and so on. Influenced by the RGB misalignment in the scanning process and the quality of the original map, large numbers of scattered colours and noises are generated in a scanned colour map. For instance, when a brown colour patch is scanned into a computer, many scattered colour pixels such as light brown, yellowish brown, dark brown are generated, which do not exist in the original map. In addition, cartographic features in different colours are more likely to overlap and intersect one another. These factors cause the phenomenon that features in the same layer do not have the same colour and similar colours do not represent the same feature layer, and therefore introduce great difficulty for colour segmentation based on colour information. Figure 1 shows a part of a colour topographic map with relief shadings and the result of segmented contour line layer. It shows that shading areas adhere together and a large number of broken lines occur in colour segmented layer. Therefore, automatic vectorization can not be performed at all in such low quality image.

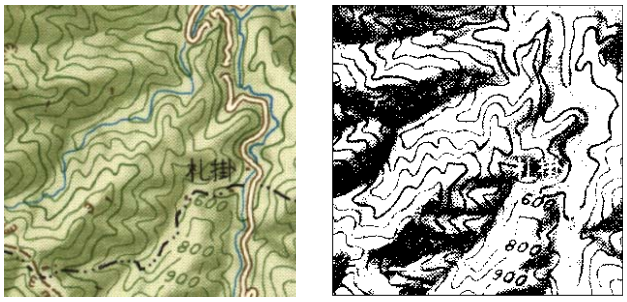

(a) (b)

Figure 1. A part of a colour topographic map with relief shadings. **a** Original image. **b** The colour segmentation result of contour line layer

3. THE PROPOSED APPROACH

The objective of our work is to find a way of vectorizing linear features directly in original colour map images without colour segmentation. How to distinguish linear features adaptively from the complicated background and how to track linear features rapidly are the key problems to be solved. In a colour topographic map image, different regions usually show marked differences in colour, brightness and contrast, especially those regions with forest tints and relief shadings. So it is difficult to distinguish linear features from the background using a global method. Considering this, we propose a local adaptive segmentation method based on sliding window to separate linear features from background, followed by a sequential line tracking to vectorize linear features.

Figure 2 shows the procedure of linear feature vectorization. For a specified linear feature, a starting point and initial direction are first input by the operator, and a predefined rectangle window (which is called sliding window) is added on the line. Then, adaptive image segmentation, thinning, and line tracking are performed in the window. By moving the window continuously along the line and doing the above operations iteratively, the line is tracked sequentially until an endpoint or an intersection is met. If the tracking is broken or a tracking error occurs before arriving at the end of the line, manual operation is necessary to cross the intersection or move back to the correct position. After that, the sequential line tracking continues until the whole line has been vectorized.

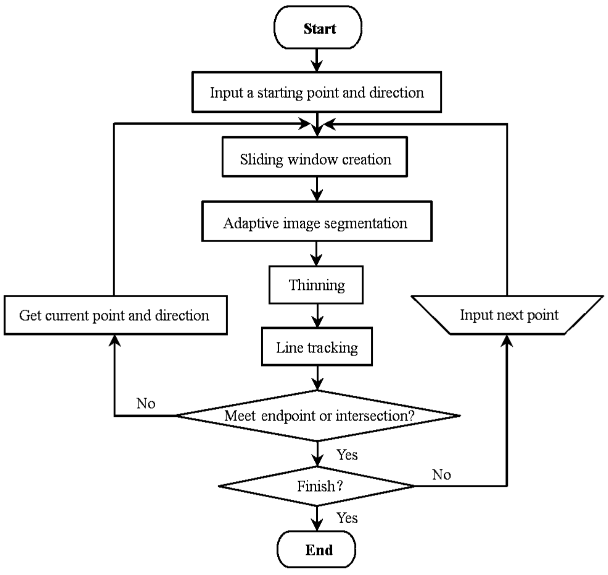

Start
Input a starting point and direction
Sliding window creation
Adaptive image segmentation
Thinning
Get current point and direction
Input next point
Line tracking
No
Meet endpoint or intersection?
Yes
Finish?
No
Yes
End

Figure 2. The procedure of linear feature vectorization

3.1 Adaptive image segmentation based on sliding window

In this study, image segmentation aims at separating a specified linear feature from colour map image. The proposed approach is applied to the aforementioned sliding window, and is performed by using colour space conversion, k-means clustering and directional region growing.

3.1.1 Colour space conversion: Since there are numerous colours in a scanned colour map image, we first convert the colour image in the sliding window into a 256 grey-scale image so as to reduce the complexity of the problem. This is due to the following considerations: Firstly, colour confusion can be improved in the image with limited grey-scale. Secondly, it is relatively easy to separate objects from the grey-scale image because there is a marked contrast between foreground and background.

YIQ colour space is adopted here on account of its advantage of separating grey-scale information from colour data. In the YIQ colour space, image data consists of three components: luminance (Y), hue (I), and saturation (Q). The first component represents grey-scale information, while the last two components represent colour information. By converting an

RGB image into YIQ format, the grey-scale information can be extracted without loss (Chen et al., 2000).

The conversion from RGB to YIQ (Ford et al., 1998) can be expressed as

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

where Y component is the grey-scale value converted from RGB value. Figure 3a and 3b shows the colour image and the converted grey-scale image in a 25 × 25 sliding window of Figure 1a.

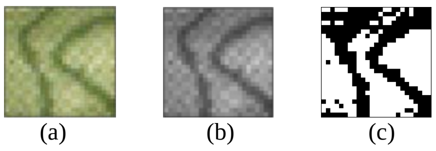


Figure 3. The image in a 25 × 25 sliding window. **a** Colour image. **b** Gray-scale image. **c** Segmentation by thresholding

3.1.2 Adaptive image segmentation: The commonly used segmentation approaches to grey-scale images include thresholding, feature space clustering, region growing, etc. Segmentation by thresholding is particularly useful for images containing objects resting upon contrasting background. But for a colour map image with many colour confusions, the converted grey-scale image may not have obvious valley in the histogram. So it is difficult to separate objects from background by using the theoretical optimal threshold, especially for the image with low contrast and low Signal-to-Noise Ratio (SNR). Figure 3c is the experimental result using Otsu thresholding method (Fu, 2001) for image segmentation. It can be seen that the lines in the window are bordered with noises and adhesions.

In order to achieve satisfying segmentation effect, this paper presents an adaptive image segmentation algorithm. The algorithm combines k-means clustering with directional region growing to segment the specified linear feature in the sliding window. First, k-means clustering is applied to a small neighbourhood (5 × 5) in the centre of the sliding window, and the pixels within the neighbourhood are divided into two regions of object and background. Then, the object region is expanded to the whole window by using directional region growing.. The reason why 5 × 5 neighbourhood is selected is that there are just only a single line in that small region, considering the line width and the distance between two lines in a topographic map image with a resolution of 300dpi. The neighbourhood should be correspondingly adjusted with the variation of linear feature width and the resolution of map image. K-means clustering is applied here because it is one of the simplest unsupervised learning algorithms for solving clustering problem (Wagstaff et al., 2001). K-means clustering and directional region growing are performed automatically in the sliding window no matter how the brightness changes, therefore it is an adaptive segmentation algorithm.

K-means clustering

The process of k-means clustering is as follows.

Step 1: Choose the pixel with minimum grey-scale as a seed within a 5 × 5 neighbourhood in the centre of the sliding window.

Step 2: Find the maximum and minimum grey-scale values in the 5 × 5 neighbourhood of the seed pixel, and let them be the initial clustering centre c_1 and c_2 of the object and background region respectively.

Step 3: For each pixel with grey-scale g_{ij} in the neighbourhood, calculate $d_1 = |g_{ij} - c_1|$ and $d_2 = |g_{ij} - c_2|$. If $d_1 < d_2$, then the pixel belongs to the object region, otherwise the background region.

Step 4: Calculate the average grey-scales m_1 and m_2 of the object and background region respectively. If they converge to c_1 and c_2, the clustering ends; otherwise, let m_1 and m_2 be the new clustering centre c_1 and c_2, go to Step 3.

Step 5: Set all the grey-scale values of the pixels belonging to the target region within the 5 × 5 neighbourhood to be 1.

For the grey-scale matrix of Figure 3b, k-means clustering is performed in the 5 × 5 neighbourhood of the seed pixel (Its grey-scale value is 105). Figure 4 shows the object and background region after k-means clustering.

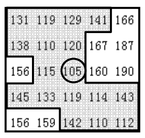


Figure 4. K-means clustering within a 5 × 5 neighbourhood

Directional region growing

Based on the k-means clustering result, directional region growing is performed in the whole sliding window. Before presenting the algorithm, the initial direction given by the operator is transformed into eight discrete directions d_1, d_2, …, d_8 (as shown in Figure 5a), and the four sides of a 5 × 5 neighbourhood centred at a seed pixel are defined as L_1, L_3, L_5 and L_7 (as shown in Figure 5b).

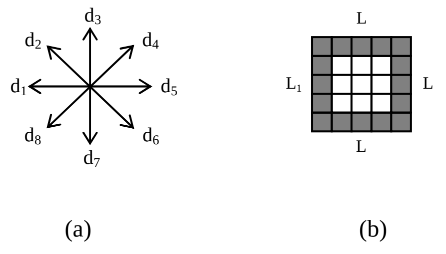


Figure 5. **a** Eight discrete directions. **b** The four sides of a 5×5 neighbourhood

The directional region growing is described as follows.

Step 1: Initialization.

① Find the pixel with minimum original grey-scale value along L_i (i=1,3,5,7) within the target region as a new seed if the initial direction is d_i (i=1,3,5,7).
② Find the pixel with minimum original grey-scale value along L_{i-1} and L_{i+1} (i=2,4,6,8; $L_{8+1}=L_1$) within the target region as a new seed if the initial direction is d_i (i=2,4,6,8).

Step 2: Perform k-means clustering within the 5 × 5 neighbourhood of the seed, obtaining new clustering centre c_1 and c_2 .

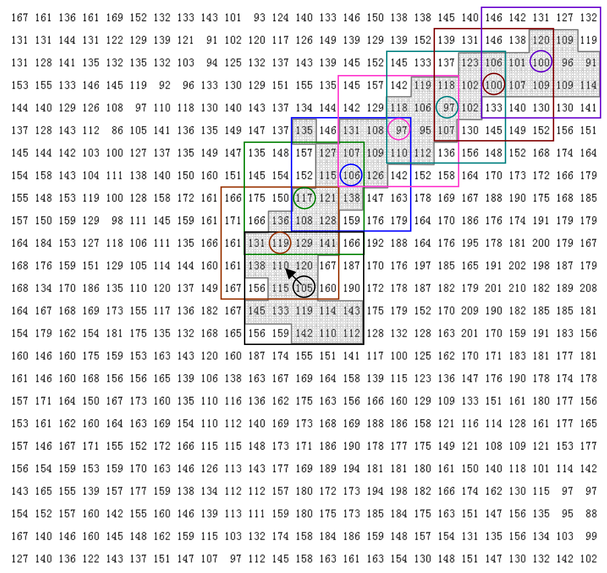
Step 3: Find the pixels in the 5×5 neighbourhood meeting the following two rules, add them into the object region, and set their grey-scale values to be 1.
Rule 1. The grey-scale difference between the pixel and the object clustering centre is smaller than that between the pixel and background clustering centre, i.e., $\left|g_{ij} - c_1\right| < \left|g_{ij} - c_2\right|$.
Rule 2. There is at least one pixel with binary value 1 in the 8-neighborhood.

Step 4: Find the pixel with minimum original grey-scale value in those pixels belonging to the newly grown target region at the four sides of the 5×5 neighbourhood as a new seed.

Step 5: Repeat Step2-Step4 until the edge of the sliding window is reached.

Step 6: Set the grey-scale values of pixels belonging to the background region to be 0.

After the above steps, the segmentation result in the sliding window is obtained (see Figure 6).



167	161	136	161	169	152	132	133	143	101	93	124	140	133	146	150	138	138	145	140	146	142	131	127	132
131	131	144	131	122	129	139	121	91	102	120	117	126	149	139	129	139	152	139	131	146	138	120	109	119
131	128	141	135	132	135	132	103	94	125	132	137	143	139	145	152	145	133	137	123	106	101	100	96	91
153	155	133	146	145	119	92	96	133	130	129	151	155	135	145	157	142	119	118	102	100	107	109	109	114
144	140	129	126	108	97	110	118	130	140	143	137	134	144	142	129	118	106	97	102	133	140	130	130	141
137	128	143	112	86	105	141	136	135	149	147	137	135	146	131	108	97	95	107	130	145	149	152	156	151
145	144	142	103	100	127	137	135	149	147	135	148	157	127	107	109	110	112	136	156	148	152	168	174	164
154	158	143	104	111	138	140	150	160	151	145	154	152	115	106	126	142	152	158	164	170	173	172	166	179
155	148	153	119	100	128	158	172	161	166	175	150	117	121	138	147	163	178	169	167	188	190	175	168	185
157	150	159	129	98	111	145	159	161	171	166	136	108	128	159	176	179	164	170	186	176	174	191	179	179
164	184	153	127	118	106	111	135	166	161	131	119	129	141	166	192	188	164	176	195	178	181	200	179	167
168	176	159	151	129	105	114	144	160	161	138	110	120	167	187	170	176	197	185	165	191	202	198	187	179
168	134	170	186	135	110	120	137	149	167	156	115	105	160	190	172	178	187	182	179	201	210	182	189	208
164	167	168	169	173	155	117	136	182	167	145	133	119	114	143	175	179	152	170	209	190	182	185	185	181
154	179	162	154	181	175	135	132	168	165	156	159	142	110	112	128	132	128	163	201	170	159	191	183	156
160	146	160	175	159	153	163	143	120	160	187	174	155	151	141	117	100	125	162	170	171	183	181	177	181
161	146	160	168	156	156	165	139	106	138	163	167	169	164	158	139	115	123	136	147	176	190	178	174	178
157	171	164	150	167	173	160	135	110	116	136	162	175	163	156	166	160	129	109	133	151	161	180	177	156
153	161	162	160	164	163	169	154	110	112	140	169	173	168	169	188	186	158	121	116	114	128	161	177	165
157	146	167	171	155	152	172	166	115	115	148	173	171	186	190	178	177	175	149	121	108	109	121	153	177
156	154	159	153	159	170	163	146	126	113	143	177	169	189	194	181	181	180	161	150	140	118	101	114	142
143	165	155	139	157	177	159	138	134	112	112	157	180	172	173	194	198	182	166	174	162	130	115	97	97
154	152	157	160	142	155	160	146	139	113	111	159	180	175	173	185	184	175	163	151	147	156	135	95	88
167	140	146	160	145	148	162	159	115	103	132	174	158	184	186	159	148	157	154	131	135	156	134	103	99
127	140	136	122	143	137	151	147	107	97	112	145	158	163	161	163	154	130	148	151	147	130	132	142	102

Figure 6. K-means clustering and directional region growing in the sliding window

3.2 Sequential line tracking

After image segmentation, a thinning operation is performed, followed by a line tracking process in the sliding window. By moving the window continuously along the line and doing the above operations iteratively, the line is tracked sequentially until an endpoint or an intersection is met.

Before giving the algorithm, we first introduce several terms in binary thinned images (see Figure 7).

Endpoint： The point with one black pixel in the 3 × 3 neighbourhood.
Connecting point： The point with two black pixels in the 3×3 neighbourhood.
Crossing point： The point with more than three black pixels in the 3×3 neighbourhood.

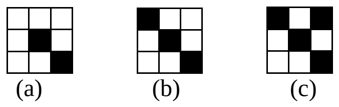


Figure 7. **a** Endpoint. **b** Connecting point. **c** Crossing point

The sequential line tracking algorithm is described as follows.

Step 1: Find a connecting point P_0 as the starting point in a 3×3 neighbourhood in the centre area of the sliding window.

Step 2: Select a point from the two black pixels in the 3×3 neighbourhood of P_0 with a close direction d to the current direction (The initial direction is input by a human operator).

Step 3: Make the current point invisible (set it to be white), and track to the next point P_i in direction d（i is counted from 1）.

Step 4: Distinguish P_i in 3×3 neighbourhood. There are three cases as follows.
① If P_i is a connecting point, there remains only one black pixel in its 3×3 neighbourhood but the invisible point, use its direction as tracking direction d, go to Step 3.
② If P_i is a crossing point, judge that it is a true or pseudo crossing point (more is said about this in the following). If it is true, stop tracking; otherwise, judge the forward direction d, go to Step 3.
③ If P_i is an endpoint or a side point of the sliding window, go to Step 5.

Step 5: Count the number of the tracking points. If it is less than 3, stop tracking; otherwise, move the centre of the sliding window to the current point, and restart Step 1.

In the above process, crossing points may be encountered due to intersections between different linear features, or due to noise. The former is called true crossing point while the latter is called pseudo crossing point. When a true crossing point is met, automatic line tracking stops for a moment, and the next point is input manually. After that, the line tracking continues as before. When a pseudo crossing point is met, an automatic judgment of forward direction is needed to across the pseudo crossing point.

To handle the pseudo crossing point, a concentration degree $\sum f_{ij}$ is defined, which means the total number of black pixels within a limited region. Suppose that S is the point in the un-thinned binary image corresponding to the crossing point P. If the concentration degree around S is larger than a preset value, then P is treated as a true crossing point. Otherwise it is a pseudo one. For topographic maps with resolution of 300 dpi, the concentration degree can be set as 20 within a 5×5 region. When meeting a pseudo crossing point, a trial-tracking is done to determine the next tracking direction. As shown in Figure 8, there are two forward directions *d1* and *d2* at the pseudo crossing point *P*. First, three connecting pixels along *d1* and *d2* are tracked respectively, and each of their corresponding grey-scale values in the grey-scale image are recorded. Then, the average grey-scale values are calculated for *d1* and *d2*, respectively. If the former is smaller, *d1* is determined as the next tracking direction, else *d2*.

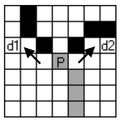


Figure 8. Determination of the forward direction at a pseudo crossing point

Figure 9 illustrates the continuous sliding window and sequential line tracking from the starting point with an initial direction pointed by the arrow. Figure 10 shows the results of image segmentation, thinning and line tracking in window 1−6 in Figure 9a. The grey line marked in each window draws a tracking path. By connecting all the grey lines in order, the tracking result is obtained (see Figure 9b).

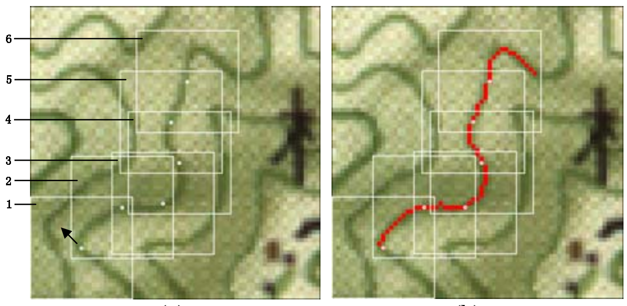
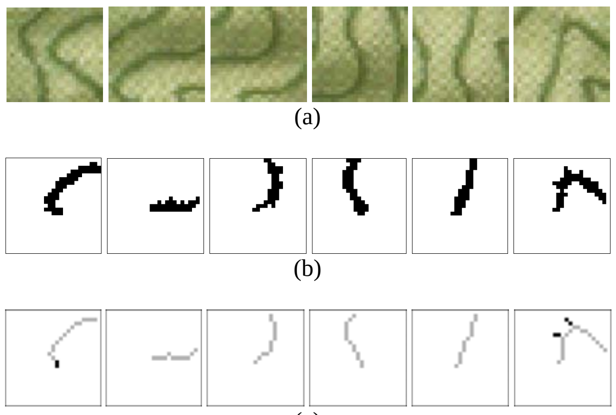


Figure 9. Sequential line tracking. **a** Continuous sliding window. **b** The result of line tracking

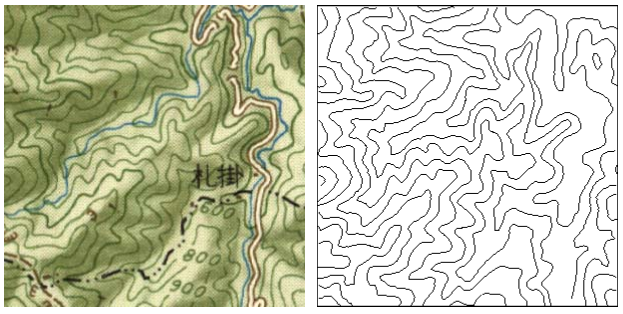


(c)

Figure 10. **a** Images in window 1-6 in Figure 9a. **b** Corresponding segmentation results of current linear feature. **c** Corresponding results of thinning and line tracking

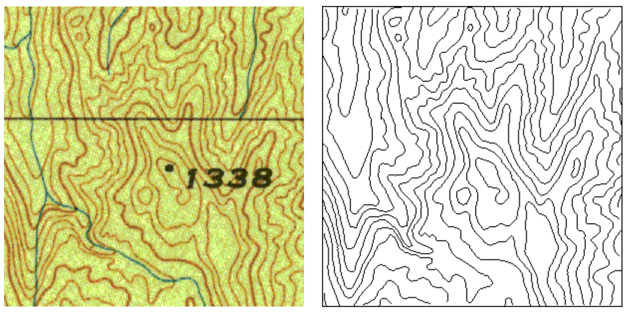
4. EXPERIMENTS AND ANALYSIS

Experiments have been conducted to test our proposed method. Figure 11a is a part of a topographic map with relief shadings. The size of the image is 300×300 pixels, the resolution is 300 dpi, and the sliding window is 25×25 pixels. For each contour line, once a starting point and direction are input by a human operator, it can be tracked automatically. In the case that an intersection or a gap is met, automatic tracking stops, and a new point in the front is input manually. After that, the line tracking continues. If the gap is wider, a few points should be collected manually to get over it, and then automatic tracking resumes. Figure 11b is the vectorization result of contour lines. Figure 12a is a part of another topographic map with forest tints. The image size, the scanning resolution, and the window size remain unchanged. Figure 12b is the vectorization result of contour lines. The average time of vectorizing contour lines in Figure 11 and Figure 12 are 200 seconds and 160 seconds respectively on a 3 GHz Pentium (R) 4 computer. Most of the time was taken by manual input of starting points and some interventions during the tracking process, while the time required by automatic tracking is negligible.



(a) (b)

Figure 11. A part of a scanned colour topographic map with relief shadings. **a** Original image. **b** Vectorization result of contour lines



(a) (b)

Figure 12. A part of another topographic map with forest tints. **a** Colour scanned image. **b** Vectorization result of contour lines

A mass of other maps including colour, grey and black-and-white maps have been vectorized, and satisfactory results have been achieved. The experiments shows that the proposed method is of great practical value in vectorizing linear features directly in original topographic map images especially those colour maps with forest tints and relief shadings.

Furthermore, a comparison with commercial software MapGIS has been made. For scanned colour maps with clear contrast between topographic features and background, it took nearly the same time to vectorize linear features by using our method and MapGIS. But for map images with low contrast and low SNR, our method is obviously efficient. It took about 9 minutes to vectorize counter lines in Figure 11 by using MapGIS, apparently slower than our method. Tracking errors (as shown in the white circle marked areas in Figure 13) often occur in the process of vectorization, and more human interventions are needed to handle these problems.

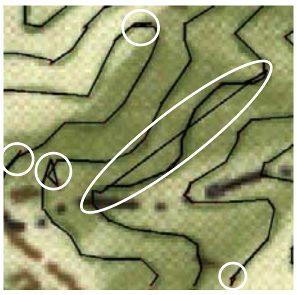


Figure 13. Vectorization result of Figure 11 by MAPGIS (locally enlarged）

From the experiments, the proposed method demonstrates the following advantages:

(1) Most of the work of line tracking can be finished automatically while human operators only need to give the starting point and the directional point. Some kinds of manual interventions are allowed in case automatic tracking fails, which makes line tracking under human control, and provides the ability to correct data immediately if required.

(2) Linear features can be tracked accurately along the centerline after image segmentation and thinning. This can avoid deviation from the centerline using only colour distance to determine the tracking point.

(3) The sliding window is updated continuously and the segmentation result in each window depends on the grey-level distribution and spatial relationship of pixels in current window. This makes line tracking adapt to colour variations in light and shade areas.

5. CONCLUSION

This paper presents a method for linear feature vectorization directly in scanned colour maps. It has been proved to be valid and practical, especially for those maps with forest tints and relief shadings. The process of sliding window creation, adaptive image segmentation, thinning and sequential tracking can be used as general steps for colour map vectorization. Future improvement mainly focuses on automatic tracking across the intersections of different linear features so as to reduce human intervention and improve the speed of vectorization.

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