Linear Feature Separation from Topographic Maps Using Energy Density and the Shear Transform

Qiguang Miao, Pengfei Xu, Tiange Liu, Yun Yang, Junying Zhang, and Weisheng Li

***Abstract*—Linear features are difficult to be separated from complicated background in color scanned topographic maps, especially when the color of linear features approximate to that of background in some particular images. This paper presents a method, which is based on energy density and the shear transform, for the separation of lines from background. First, the shear transform, which could add the directional characteristics of the lines, is introduced to overcome the disadvantage that linear information loss would happen if the separation method is used in an image, which is in only one direction. Then templates in the horizontal and vertical directions are built to separate lines from background on account of the fact that the energy concentration of the lines usually reaches a higher level than that of the background in the negtive image. Furthermore, the remaining grid background can be wiped off by grid templates matching. The isolated patches, which include only one pixel or less than ten pixels, are removed according to the connected region area measurement. Finally, using the union operation, the linear features obtained in different sheared images could supplement each other, thus the lines of the final result are more complete. The basic property of this method is introducing the energy density instead of color information commonly used in traditional methods. The experiment results indicate that the proposed method could distinguish the linear features from the background more effectively, and obtain good results for its ability in changing the directions of the lines with the shear transform.**

***Index Terms*—Background, color information, energy density, linear feature, map image, shear transform, template matching, union operation.**

I. Introduction

THE digitization of topographic maps is an important data source of constructing Geographical Information Systems (GIS). These maps consist of linear features (such as contour lines and roads) and background (such as background fields, green fields and bodies of water). Because linear features are fundamental to many GIS based planning applications, and detailed lines information can be tedious and time-consuming to be digitized manually, automated extraction of lines will improve the productivity of the digitizing process [1], [2]. But automatic separation of linear features from background in these maps poses a substantial challenge due to the heavy interconnection of them [3]. In most maps, different geographic features are represented by different colors, and the differences between their color information are obvious, so they can be separated from each other on the basis of color similarity. However, in other particular maps, the colors of different geographic features are close to each other. Furthermore, there are additional challenges to the solution of the existing problems because of the introduction of aliasing and false colors during the scanning process [4], [5].

The majority of the traditional methods for cartographic feature separation from topographic maps are based on color information [6]–[9]. Feng.etc proposed a method for feature separation based on color clustering [10]. Ebi.etc presented a method for the purpose of making better use of the color information by converting the RGB color space into other color spaces [11]. Considering the existence of aliasing and false colors, Wu.etc proposed a method based on fuzzy theory, which combines fuzzy clustering and neural networks for the extraction of the lines and characters [12]. Zheng.etc presented a method of fuzzy clustering based on a 2-D histogram [13]. Aria Pezeshk.etc presented a semi-automatic method to extract contour lines from scanned color topographic maps, in the proposed method, contour lines are removed from the image using a algorithm based on quantization of the intensity image followed by contrast limited adaptive histogram equalization [14]. In order to make full use of the information of color space, local homogeneity and connected regions of color layers, S. Leyk proposed a segmentation method, which uses information from the local image plane, the frequency domain and color space (RGB) [15], [16], lines acquired by this method are more continuous and complete. And there are other separated methods which are based on color similarity and HSV color space [17], [18]. Based on the research of these methods, the idea behind these algorithms, which could have a good performance for the maps whose color difference is obvious, is that color information of the maps is used to separate lines from background; the basic feature of these color segmentation methods is color similarity. Nevertheless, in the particular maps, the colors of lines and background are close to each other, thus these methods would not work well.

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Q. Miao, P. Xu, T. Liu, and J. Zhang are with the School of Computer, Xidian University, Xi'an, Shaanxi 710071, China (e-mail: qgmiao@126.com; xpf1987071500@126.com; liutiange@126.com; jyzhang@mail.xidian.edu.cn).

Y. Yang is with the Xi'an Research Institute of Surveying and Mapping, Xi'an, Shaanxi 710054, China, and with the State Key Laboratory of Geo-Information Engineering, Xi'an, Shaanxi 710054, China (e-mail: yytoall@126.com).

W. Li is with the College of Computer Science and Technology, Chongqing University of Posts and Telecommunications, Chongqing 400065, China (e-mail: liws@cqupt.edu.cn).

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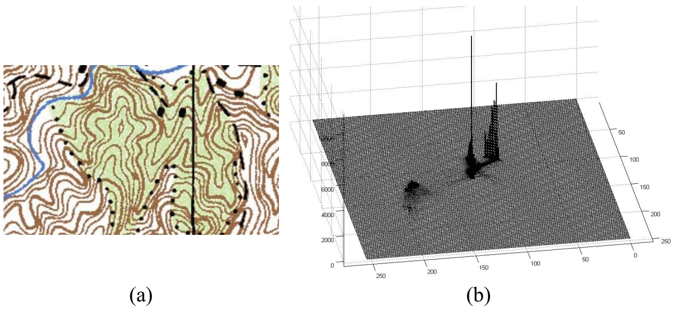


Fig. 1. Analysis of the color information for a general image. (a) Original image. (b) Histogram of a and b channels in lab color space.

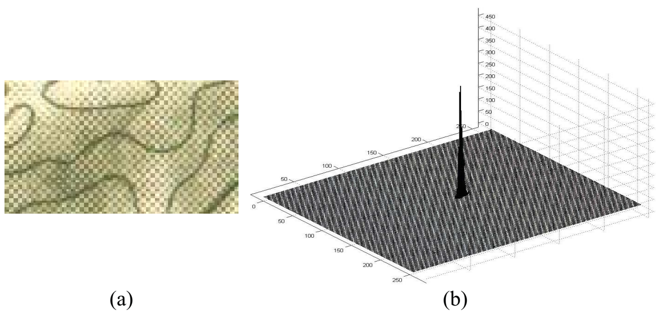


Fig. 2. Analysis of the color information for a particular image. (a) Original image. (b) Histogram of a and b channels in lab color space.

In the binary images of maps, the separation method for the lines and background based on grid templates is mainly applied to the maps containing background features which have grid distribution in an ideal situation [19]. However, this method cannot work well when the distribution of background features is very complicated.

In order to overcome these problems, this paper proposes a method for linear separation from background. In the method, the energy density concept is proposed to describe the energy distribution of linear features and background, then the shear transform is introduced to offer discretized directionality of lines, then the lines can be separated from the background on the basis of the combination of them. The experiments show that the new method can be efficiently implemented for the actual map images, and linear features can be separated more completely and effectively than those available.

The organization of this paper is as follows: In the Section II, we make a characteristic analysis of linear features and background on the following three aspects: the color histograms of map images, the distribution of background in the binary image of the maps and the energy histograms of linear features and background. The proposed method is described in detail in Section III, it includes the proposition of the energy density, the introduction of the shear transform and their combination which is the method proposed in this paper. In Section IV, we compare the experimental results among different state-of-the-art techniques, and show that the method we propose yields significantly preferable outcomes. Finally, the concluding remarks are given in Section V.

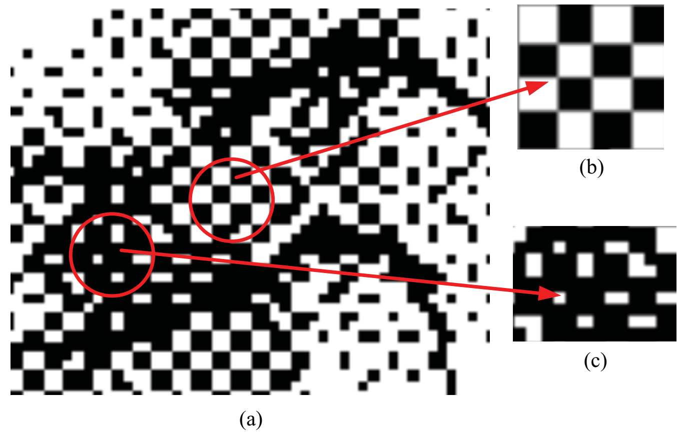


Fig. 3. Analysis of background in the binary image. (a) Binary image. (b) Ideal background. (c) Complicated background.

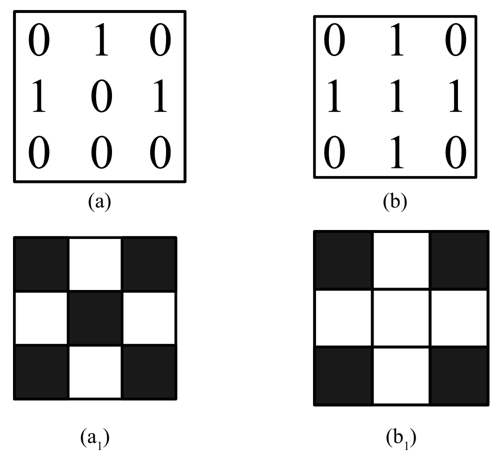


Fig. 4. Grid templates used to remove grid background.

II. Characteristic Analysis of Linear Features and Background

The reasons why the separation methods mentioned in Section I cannot separate lines from background effectively would be analyzed in color information of the images. Fig. 1(b) is the color histogram of an original image (shown in Fig. 1(a)) in Lab color space, in which the difference of the color is obvious, there are several peaks in the color histogram. In contrast, Fig. 2(b) is the color histogram of another original image (shown in Fig. 2(a)) in Lab color space, in which the color of the pixels are close to each other, there is only one peak in the color histogram. So the traditional methods based on color information cannot separate different geographic elements because of their similar colors.

The analysis of the binary image is shown in Fig. 3. It can be seen that the distribution of background is very complicated. The background in some regions is distributed regularly (shown in Fig. 3(b)), then the grid templates [19] which are shown in Fig. 4 can be used to remove this kind of grid background. If a center pixel and its 8-neighborhood satisfied the situation which is shown in Fig. 4(a) and 4(a1) is the corresponding condition in the binary image (The black represents 0 and the white 1), then the center pixel would

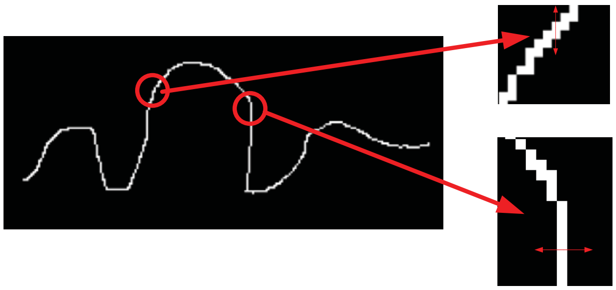


Fig. 5. Distribution of lines and background in the ideal case.

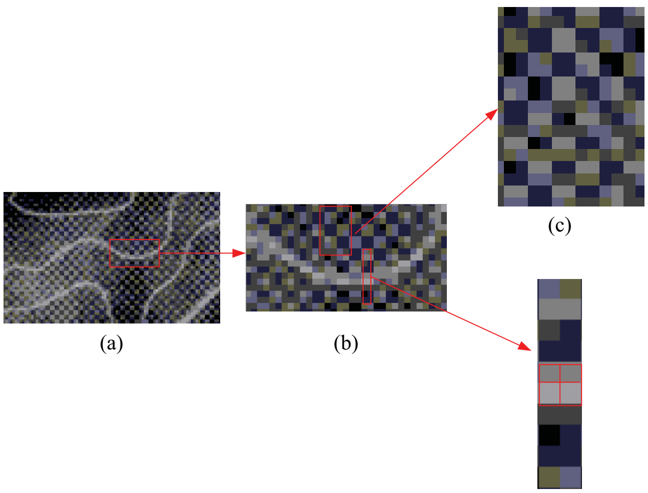


Fig. 6. Distribution of lines and background in the actual case. (a) Actual image. (b) Magnified image of the sub-region labeled by the red box in (a). (c) and (d) Magnified images of the sub-regions labeled by the red boxes in (b).

be judged as a background pixel and removed with its value as 1, the result is shown in Fig. 4(b), and the corresponding condition in the binary image is shown in Fig. 4(b1). While in some other regions it is more complicated (shown in Fig. 3(c)), so this method cannot work well.

On the basis of the analysis above, it is necessary to explore other characteristics of linear features and background instead. In this paper, we focus on their energy characteristics [20]. The energy E of an image f is defined as follows:

$$E = \sum_{(i,j)} f^2(i, j)$$

where $i = 1, 2, \ldots, M;\ j = 1, 2, \ldots, N;\ M, N$ are the height and width of the image respectively. Because of the correlations between a pixel and its neighborhood pixels, the local energy E' of a pixel $f(i, j)$ can be defined as the energy of the window in the domain:

$$E' = \sum_{(m,n)} f^2(m, n)$$

where $i - k \leq m \leq i + k, j - k \leq n \leq j + k$, the width of the window is $w(w = 2k + 1)$. The difference between E and E' is that E is the energy of the whole image, while E' is the local energy of one pixel.

In the ideal case, the energy of a binary image is almost concentrated on the lines as shown in Fig. 5, and that is similar to the actual case (shown in Fig. 6). Fig. 6(c) and 6(d) are the magnified images of the sub-regions labeled by the red boxes in Fig. 6(b), and represent the background and the difference between lines and background respectively. There is a significant difference of energy concentration between the lines and background, the energy of the lines in an actual image has much higher aggregation degree than that of the background.

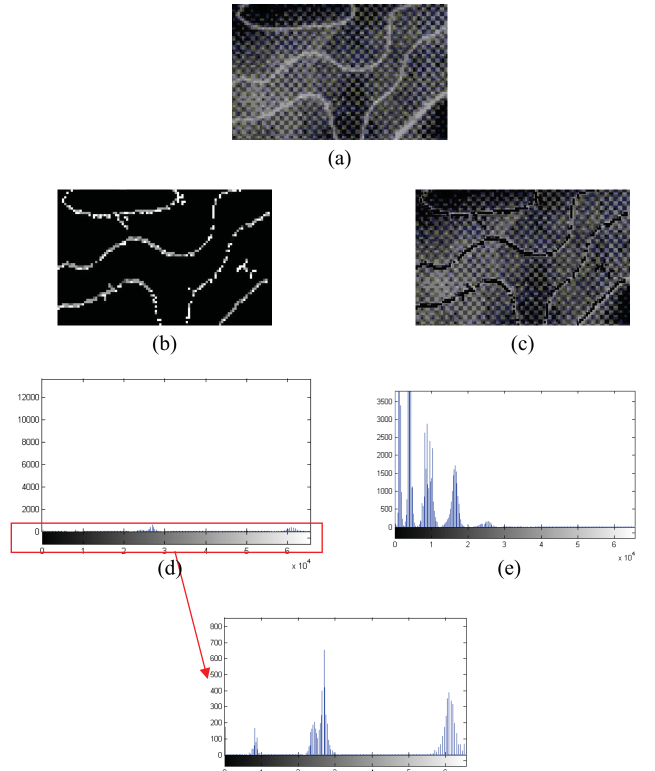


Fig. 7. Analysis of the energy histograms. (a) Actual image. (b) Lines. (c) Background. (d) Energy histogram of the lines. (e) Energy histogram of the background. (d') Local enlarged image of the energy histogram of the lines.

The analysis of the energy histograms is made here and shown in Fig. 7. Fig. 7(d) is the energy histogram of lines. It can be seen that lines although have a few pixels, all of the energy is almost concentrated on the lines, most of the line energy range from the energy value of 2.5×10^4 to 3×10^4 and some others are even larger than 6×10^4. Consequently the line energy has a high aggregation degree, which is the characteristic of lines. Fig. 7(e) is the energy histogram of background which has a large amount of pixels, and the energy of many pixels is close to that of lines, which is from 2.5×10^4 to 3×10^4, however, the energy scatters in the whole image, so it has a low aggregation degree, the characteristic of background. Thus, the energy in per unit area of the lines reaches a higher level than that of background around lines.

Lines in the gray image are dark, while according to the study of HVS (Human Vision System), the human eyes are sensitive to the brightness so that they can easily capture a bright target, the objects can be caught by the human eyes more effectively using the negative operation to the gray image. In addition, humans can distinguish the lines from background because humans can recognize the objects from the point of view of an image as a whole. Similarly, the separation of the lines from background also should be based on an area with certain size rather than a certain point.

III. Proposed Method

In most map images, different geographic features are represented by different colors, and the differences of their color information are obvious. So the traditional methods, which are on the basis of color similarity, can work well to separate geographic features. However, in some particular maps, the colors of different geographic features are close to each other; as a result color similarity fails to be used to separate geographic features. From the above views the separated method proposed in this paper is on the basis of energy density instead of color similarity.

A. Separation of Linear Features from Background

According to the characteristic analysis of the linear features and the background in the color topographical maps, the energy density concept is formulated. In a negative image, the energy density, which can reflect the degree of the energy concentration, is defined as the average energy in an area. It can be described using the following formula

$$E_d = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(f(i,j))^2}{M \times N} \tag{1}$$

where E_d is the energy density, $M \times N$ is the size of the area, $f(i,j)$ is the gray-value of a pixel in the negative image.

Then two templates for linear separation from background are built as shown in Fig. 8. The white area is the linear features corresponding to h_2 in Fig. 8(b) and 8(c), and its size is a prior data according to the information of the production of the map and determined by the width of the lines. Usually, in most map images, it can be 2×2. The rest is background corresponding to h_1 and h_3, and the size is determined by the distribution on background. Many experiments show that h_1 and h_3 with a general size 4×2 or 2×4 is appropriate for most images.

The energy density of the templates can be calculated using the equation (2):

$$E_{dk} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(f(i,j))^2}{m \times n} \qquad k = 1, 2, 3 \tag{2}$$

where E_{dk} is the energy density of each area in the templates, E_{d1}, E_{d2}, and E_{d3} are corresponding to h_1, h_2, and h_3, $m \times n$ is the size of each area in the templates. Then according to the energy density, linear features and background can be separated from each other in accordance with the following rules:

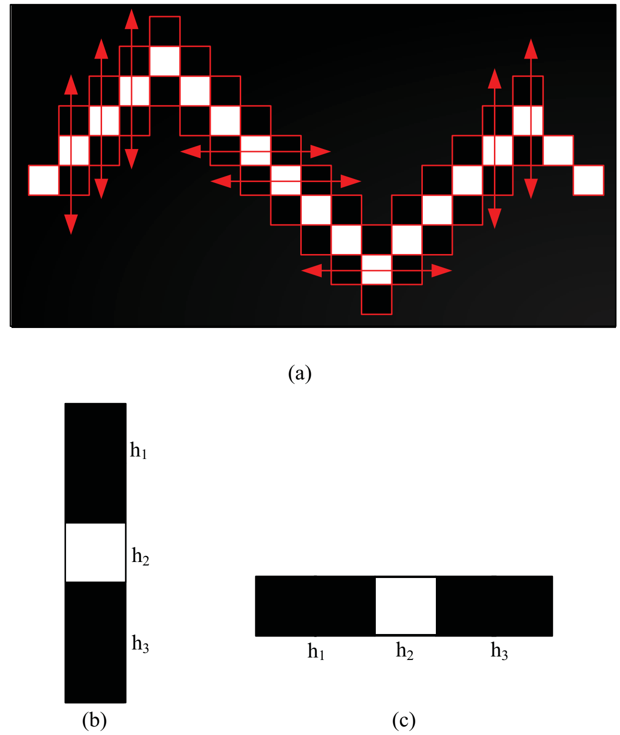


Fig. 8. Templates for linear separation. (a) Lines. (b) Template in the vertical direction. (c) Template in the horizontal direction.

1) Rule 1: The energy of the lines is distributed in a small area, the energy density is high; but the energy of the background is distributed in a large area, so the energy density is low. Therefore, lines reach a higher level of energy concentration than that of the background, and it is clear that the energy density of lines is the maximum value in the templates, that is:

$$\begin{cases} E_{d2} > E_{d1} \\ E_{d2} > E_{d3} \end{cases} \tag{3}$$

2) Rule 2: However, the lines and background cannot be separated accurately just satisfying the rule 1. It is necessary to control the difference of the energy density between lines and background to a certain range. And for this purpose, a threshold should be defined as follows:

$$\overline{E_d} = \frac{E_{d1} + E_{d2} + E_{d3}}{3}$$
$$T = E_{d2} - \overline{E_d} + \alpha$$

where $\overline{E_d}$ is the average energy density of the templates, T is the threshold, α is the controllable parameter which could be established by the specific situation of the linear features and background. The value of α can be acquired from experience, and the empirical value of α is from 3000 to 5000 for most map images. Consequently, the lines can be more accurately separated depending on the following rules:

$$\begin{cases} E_{d2} - E_{d1} > T \\ E_{d2} - E_{d3} > T \end{cases} \tag{4}$$

In the templates, h_2 can be judged as a linear feature if its energy density simultaneously meets both rule 1 and rule 2,

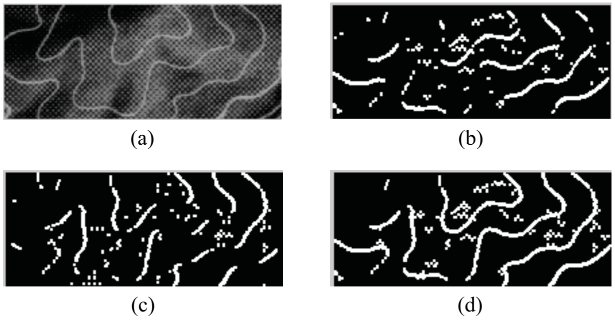


Fig. 9. Linear separation based on the energy density. (a) Negative image. (b) Lines separated using the horizontal templates. (c) Lines separated using the vertical templates. (d) Final result combining (b) and (c).

so h_1 and h_3 are backgrounds, and should be removed. The remaining grid background can be wiped off based on grid templates matching [19], which is mentioned in Section II, and the isolated patches which include only one pixel or less than ten pixels are removed according to the connected region area measurement. Finally, lines separated using the horizontal and vertical templates are combined by the union operation. Fig. 9 shows the process of linear separation based on these rules.

B. Shear Transform

As shown in Fig. 9(d), linear features are lost in the process of linear separation due to the directional limits of lines only separated in one direction image. So it is difficult for lines having many directions to separate whole complete lines from background. In order to solve this problem the shear transform [21]–[25] is introduced here.

From researching the shear transform [26], we learn that the shear transform is an affine transforms which is similar to the rotation transform. The rotation transform is a very convenient tool to provide directionality in the sense that it preserves important geometric information such as length, angles, and parallelism. However, this operator does not preserve the integer lattice, which causes severe problems for digitization. In contrast to this, the shear transform with a shear matrix does not only provide directionality, but also preserves the integer lattice when the shear parameter is integer. Thus, it is conceivable to assume that directionality can be naturally discretized by using a shear matrix. If the shear transform is applied on an image, the lines keep the characteristic of linear features, and the directional information of the lines would be more.

Let $W_{s,k}$ denote the shear operation, where $s = 0$ or 1, $k \in [-2^{(\mathrm{ndir})}, 2^{(\mathrm{ndir})}], k \in Z$, Z stands for the set of integers, and $ndir$ is the direction parameter ($\mathrm{ndir} \in N$). The sheared images $f^{'}s, k(x, y)$ are acquired by taking the shear operation on the image $f(x, y)$, and the number of which is $2 \times (2^{(\mathrm{ndir}+1)} + 1)$.

$$f^{'}_{s,k}(x, y) = f(x, y) * W_{s,k} \tag{5}$$

The shear transform is performed by sampling pixels according to the shear matrix $s_0 = \begin{bmatrix} 1 & 0 \\ \frac{\lfloor k \rfloor}{2^{ndir}} & 1 \end{bmatrix}$ or $s_1 = \begin{bmatrix} 1 & \frac{\lfloor k \rfloor}{2^{ndir}} \\ 0 & 1 \end{bmatrix}$.

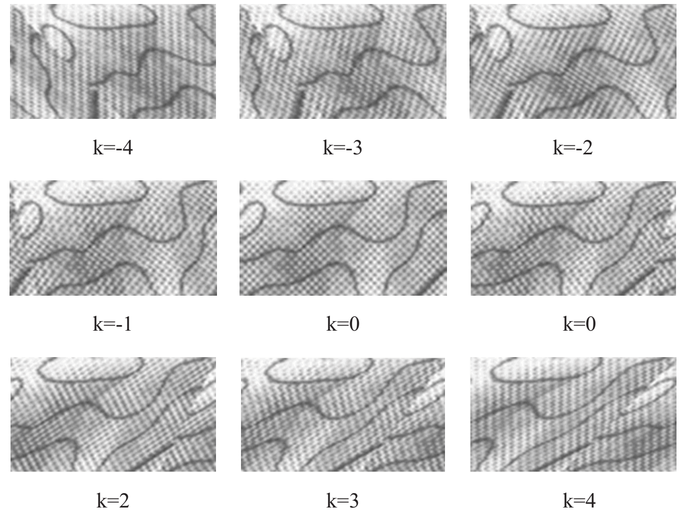


Fig. 10. Results of the shear transform.

When $s = 0$, the shear operation would be performed in the horizontal direction according to the shear matrix s_0

$$(x', y') = (x, y)\mathrm{S}_0 = (x, y)\begin{bmatrix} 1 & 0 \\ \frac{\lfloor k \rfloor}{2^{ndir}} & 1 \end{bmatrix} = \left(x + y \times \frac{\lfloor k \rfloor}{2^{\mathrm{ndir}}}, y\right) \tag{6}$$

$$f'0, k(x', y') = f(x, y) \tag{7}$$

where (x', y') is the coordinate of a pixel in the sheared image, (x, y) the coordinate of a pixel in the original image. But the values of all the pixels remain unchanged during this process. When $s = 1$, the shear transform is performed in the vertical direction according to s_1, and the procedure is similar.

After the shear transform being performed on the image $f(x, y)$, sheared images $f's, k(x', y')$ are acquired. However, in the sheared images, some parts go beyond the boundaries of the images after such processing. In this case, common sense informs us that some information lost. To solve this problem, the blank areas of the sheared images are necessary to be filled with the exceeded parts, and the final results $f''\mathrm{s}, k(x'', y'')$ are acquired. It's the same that the values of the pixels also remain unchanged during this process.

A variety of sheared images which are obtained by the shear transform are shown in Fig. 10. Here $s = 0$ and $\mathrm{ndir} = 2$, so the number of the sheared images is nine. Then based on the energy density, the lines could be separated from background in the sheared images, while the union operation is applied to obtain more complete linear features.

C. Steps of the Proposed Method

On the basis of the analysis above, this paper proposes a method based on the energy density and the shear transform for separating lines from map images with a complicated background. Then the remaining grid background can be removed using a grid template, on the other hand, the isolated patches are removed according to the connected region area measurement. The steps of this method are described as follows:

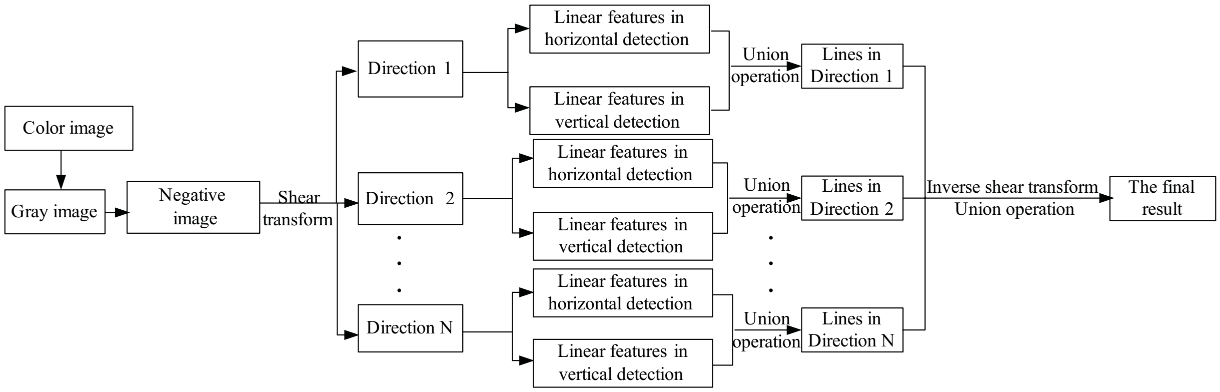


Fig. 11. Flow diagrams of linear feature separation from topographic maps using energy density and the shear transform.

1) Step 1: The color image conversion to gray scale image: The gray scale image can be obtained by formula (8)

$$Gray = 0.233R + 0.587G + 0.114B \tag{8}$$

where $Gray$ is the gray image, R, G, and B are respectively the values of three color channels. Then the negtive operation is applied to the gray scale image by equation (9), and the negative image I can be obtained.

$$I = \mathrm{e} \times 255 - Gray \tag{9}$$

where e is a matrix, and it has the same size as $Gray$, the value of all the elements is 1.

2) Step 2: Shear transform: The shear transform is applied to the negative image$I$. Here we set $s = 0$ only. Then there are $(2^{(\mathrm{ndir}+1)}+1)$ sheared images I' acquired. The implementation of the shear transform is illustrated more detail in Section B.

3) Step 3: The establishment of the templates: Templates are built in both the horizontal and the vertical directions for linear feature separation form background, which are mentioned in Section A.

4) Step 4: Linear feature separation from background: The energy density of each area in the templates is calculated at first, and then the lines could be separated from sheared images according to rule 1 and rule 2, which are mentioned in section A, and the value of α is 4000.

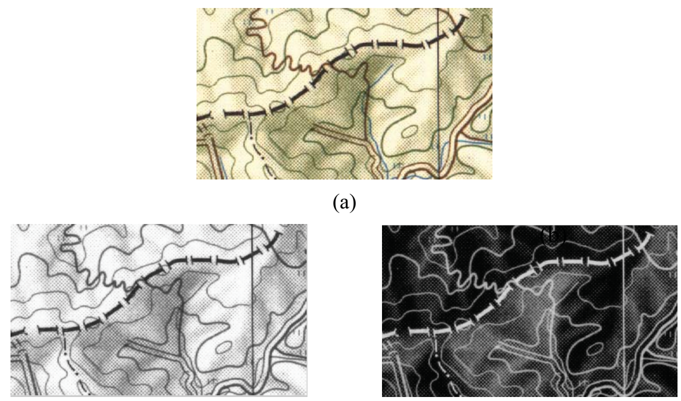
5) Step 5: The removal of miscellaneous points: The remaining grid background can be wiped off by grid template matching, which is mentioned in Section II, and the isolated patches which include one pixel or less than ten pixels are removed according to the connected region area measurement.

6) Step 6: Inverse shear transform and the union operation: The inverse shear transform is used for the images containing lines with various directions, and then all of the images are fused into the final image by the union operation.

The flow diagrams for realizing the method are shown in Fig. 11.

IV. Experiments and Discussions

Seven color topographical maps are used to verify the validity of the method. Fig. 12(a) is the original image with the size 342 × 198 for demonstrating the whole process of the method. It indicates that background pixels have a wide variation in the image and the total distribution is very complicated. Moreover, the difference of color between some of the linear features and the background is very little, hence it is very difficult to separate lines from background just based on color information.



(a)

(b) (c)

Fig. 12. Transformation of the original image. (a) Original image. (b) Gray image. (c) Negative image.

Figs. 12–14 shows the whole process. Here, the size of h_2 in the templates is determined as 2 × 2, both h_1 and h_3 are in size of 4 × 2 in the vertical direction, 2 × 4 in the horizontal direction. The controllable parameter is given as $\alpha = 4000$. Firstly, the original color image is changed into the gray image as shown in Fig. 12(b), and the negative operation is applied to the gray image. The result is shown in Fig. 12(c). Secondly, there are 3 sheared images obtained by the shear transform as shown in Fig. 13(a_1, b_1, and c_1) with ndir $= 0$. Furthermore, the lines of the sheared images are separated based on energy density by both the horizontal and the vertical templates, fused by the union operation, and the results are shown in Fig. 13(a_2, b_2 and c_2). Finally, the inverse shear transform and the union operation are applied to the images in Fig. 13(a_2, b_2 and c_2), and the final result shown in Fig. 14(a) is obtained. Fig. 14(b) is lines with color information extracted from the original color image, these lines are corresponding to those in Fig. 14(a), and used in the post processing. So the color information of the lines is reserved. Fig. 14(c) is the remaining background.

In order to prove the validity of the proposed algorithm, this section use the improved FCM clustering method based on Lab color space [13], the color segmentation method used

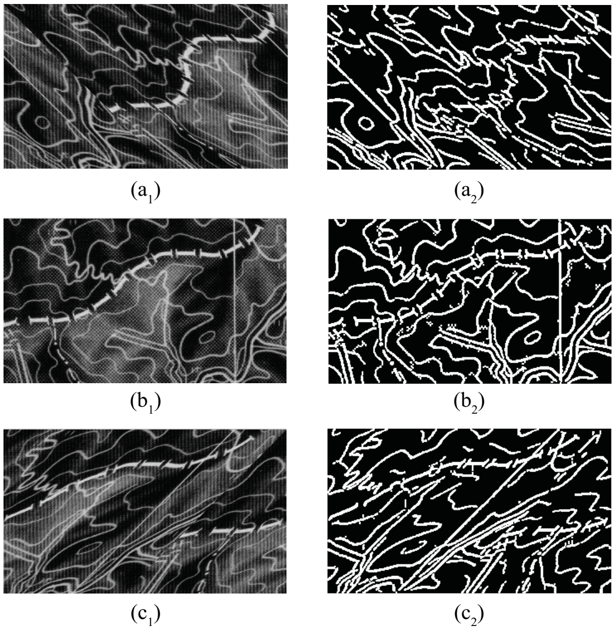


Fig. 13. Sheared images and lines separated from sheared images. (a_1) Sheared images with $k = -1$. (a_2) Separated lines with $k = -1$. (b_1) Sheared images with $k = 0$. (b_2) Separated lines with $k = 0$. (c_1) Sheared images with $k = 1$. (c_2) Separated lines with $k = 1$.

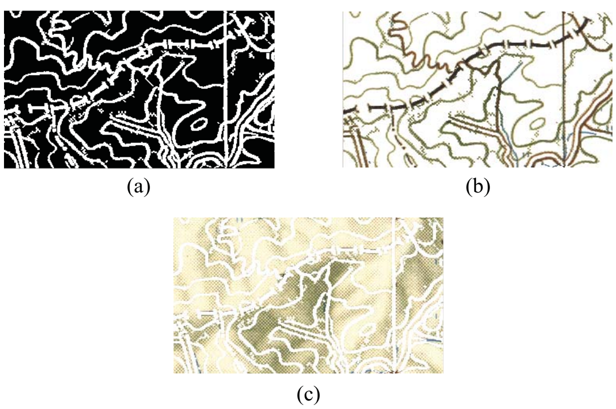


Fig. 14. Final results obtained by our method. (a) Final separated lines. (b) Lines separated from the color images. (c) Remaining background features.

in [18], the method proposed by Stefan Leyk in 2010 [15], [16] and the separated method based on energy density without the shear transform as comparison experiments.

Fig. 15(a) and Fig. 16(a_2, b_2, c_2) are the lines separated by FCM based on Lab color space, Fig. 15(b) and Fig. 16(a_3, b_3, c_3) are the lines separated by the method proposed by S. Oka [18], which is based on HSV color space. It can be seen that the lines separated by both methods are almost identical, the results still contain lots of background and some of the lines are discontinuous. But the latter one performs a little better in removing background. The primary reason for all these is that the basic features used in these color segmentation methods is color similarity, but in some particular maps, the colors of lines and background are close to each other (for example, the image shown in Fig. 12(a) and Fig. 16(a_1 and c_1)), then color similarity would become a detrimental factor for

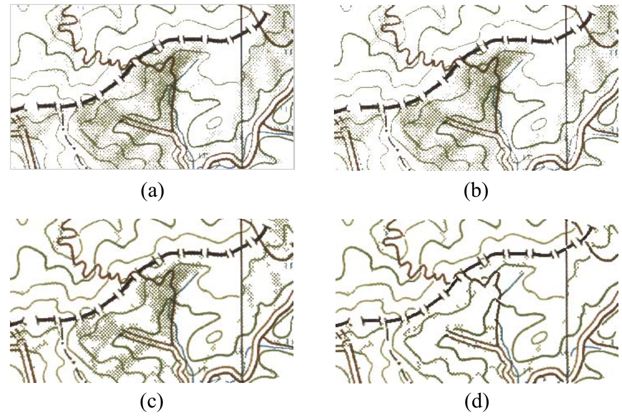


Fig. 15. Lines separated by other existing methods. (a) Lines separated by using FCM based on lab color space [13]. (b) Lines separated based on HSV color space [18]. (c) Lines separated by Leyk method [15], [16]. (d) Lines separated based on energy density without the shear transform.

segmentation methods, thus leading to the bad performance of these methods based on color information.

The approach proposed by S. Leyk uses information from the local image plane, the frequency domain and color space (RGB). The keys of this method are the iterative clustering and the constrained seeded region growing process, and the results obtained by S. Leyk's method are shown in Fig. 15(c) and Fig. 16(a_4, b_4, c_4).

Fig. 16(b_4) is the result using the method proposed by Stefan Leyk, while Fig. 16(b_6) is the result using the proposed method in the paper. The results obtained by both methods are almost the same, the lines in both two results are continuous and complete. Even in Fig. 16(b_4), the railroad is separated better than that in Fig. 16(b_6), due to the fact that the color properties of linear features and background are different in the original image (shown in Fig. 16(b_1)). In addition, the S. Leyk's method utilizes four constraints (local homogeneity, connected regions of color layers, color similarity and spatial connectivity), and applies a constrained seeded region growing process. So it can enable the homogeneous area defined on the basis of color properties expand, furthermore it can effectively separates lines from background.

However, in other particular map images, the color properties of linear features and background are close to each other, the S. Leyk's method cannot work well, although it has many advantages mentioned above. Fig. 12(a) and Fig. 16(a_1, c_1) shows the color properties of the contour lines and background are almost the same. The results obtained by this method are shown in Fig. 15(c) and Fig. 16(a_4, c_4), we can see that they are better than the results obtained by FCM; the lines are more continues and have much less patches. Contrary to the basic property that the color and space information is utilized in this method, separating contour lines from background in the map images with properties that most background has the same color as contour lines and some regions of background are connected is hard to proceed, and amounts of background is left in the final results, which is much more significant in Fig. 16(c_4).

Fig. 15(d) and Fig. 16(a_5, b_5, c_5) are the lines separated based on energy density without the shear transform, due

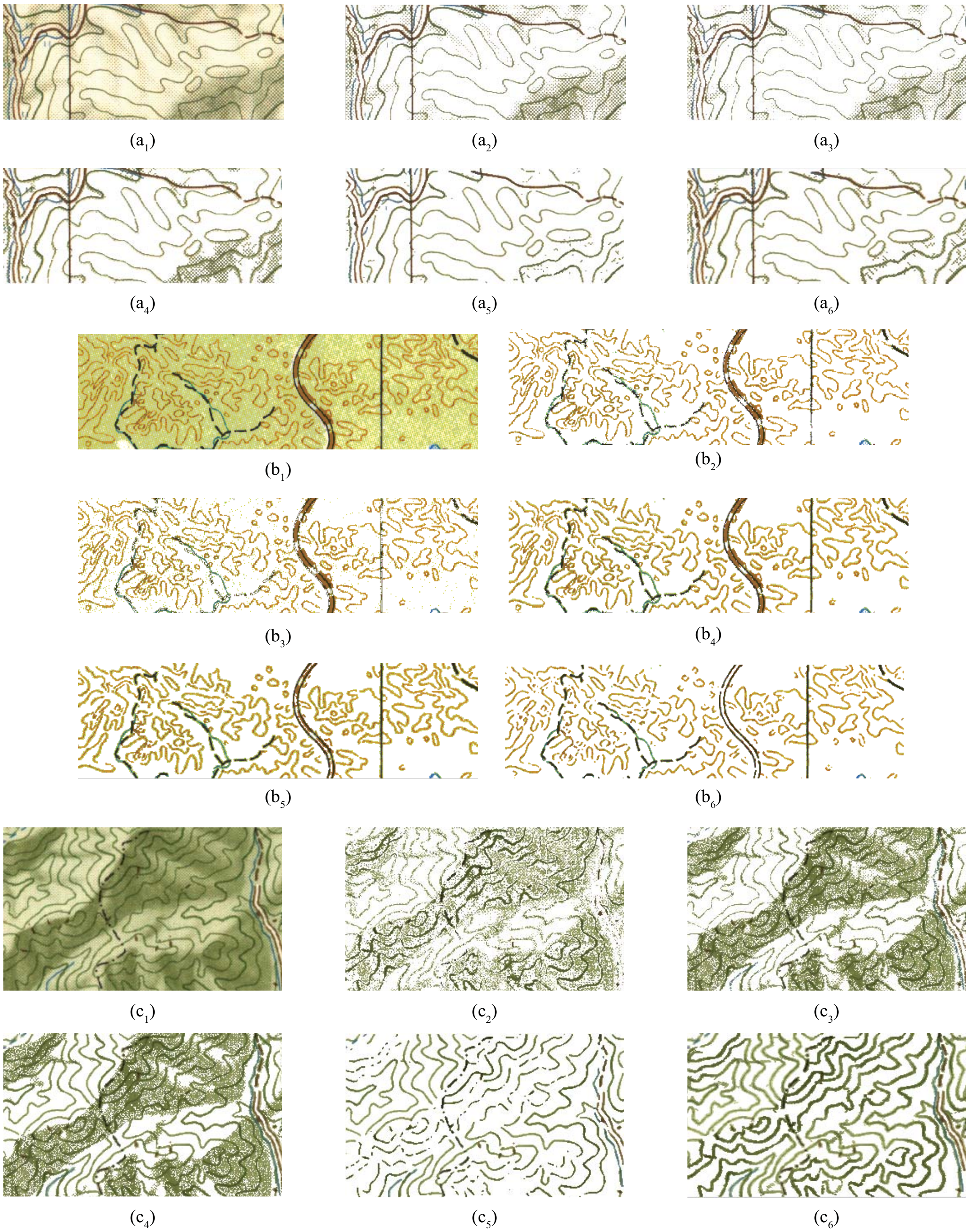


Fig. 16. Test images and the separated lines obtained by several methods. (a_1) Original image. (a_2) Lines separated by using FCM based on lab color space. (a_3) Lines separated based on HSV color space. (a_4) Lines separated by Leyk method. (a_5) Lines separated based on energy density without the shear transform. (a_6) Lines separated by our method. (b_1) Original image. (b_2) Lines separated by using FCM based on lab color space. (b_3) Lines separated based on HSV color space. (b_4) Lines separated by Leyk method. (b_5) Lines separated based on energy density without the shear transform. (b_6) Lines separated by our method. (c_1) Original image. (c_2) Lines separated by using FCM based on lab color space. (c_3) Lines separated based on HSV color space. (c_4) Lines separated by Leyk method. (c_5) Lines separated based on energy density without the shear transform. (c_6) Lines separated by our method.

to the limitation of the directions of the lines, there exists a loss of linear features and the discontinuity of lines. The final results obtained by our method are shown in Fig. 14(b) and Fig. 16(a_6, b_6 and c_6)), it can be seen that almost all the linear features can be separated from the topographical maps, and the background are removed clearly. That owes to the basic information used in this separated method is energy density instead of color similarity. Finally the comparison between these images and the corresponding ones suggests that since the shear transform could change the

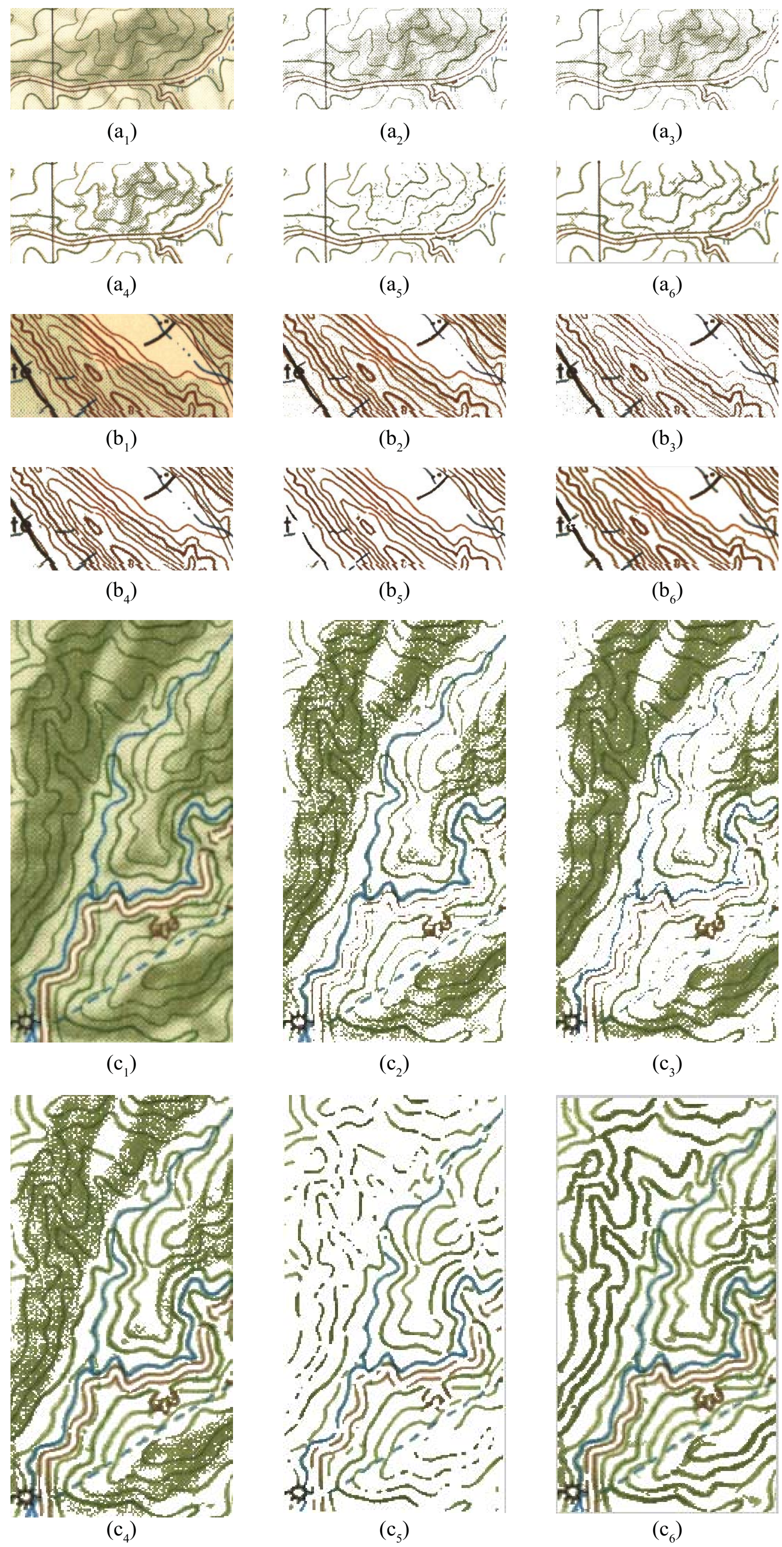


Fig. 17. Test images and the separated lines obtained by several methods. (a_1) Original image. (a_2) Lines separated by using FCM based on lab color space. (a_3) Lines separated based on HSV color space. (a_4) Lines separated by Leyk method. (a_5) Lines separated based on energy density without the shear transform. (a_6) Lines separated by our method. (b_1) Original image. (b_2) Lines separated by using FCM based on lab color space. (b_3) Lines separated based on HSV color space. (b_4) Lines separated by Leyk method. (b_5) Lines separated based on energy density without the shear transform. (b_6) Lines separated by our method. (c_1) Original image. (c_2) Lines separated by using FCM based on lab color space. (c_3) Lines separated based on HSV color space. (c_4) Lines separated by Leyk method. (c_5) Lines separated based on energy density without the shear transform. (c_6) Lines separated by our method.

directions of lines, the directional characteristics of lines are increased and the lines would be more complete and continues.

The images shown in Fig. 16(c_1) contain more complicated background information so that lines could not be separated accurately by traditional methods (as shown in Fig. 16(c_2),

(c_3) and (c_4)). But the proposed method provides a more effective way to separate lines from background.

According to the analysis above and the comparison of experimental results, it can make a conclusion that the proposed method can perform more effectively than other existing methods. In addition, there are some other experiment results shown in Fig. 17 to validate the effectiveness of the proposed method.

V. Conclusion

This paper proposes a method for linear separation from background, in this method, the shear transform is introduced to overcome the limitation of directions for lines, and the concept of energy density is proposed to describe the energy distribution of linear features and background in an image. Then the lines can be separated on the basis of the energy density and the shear transform. The new method can be efficiently implemented for the actual map images, and the experiments indicate that the proposed method can separate linear features from background more completely and effectively than those available. However, the proposed method still has several flaws which we need to do some more research later. For instance, the size of the template is determined by the width of the lines and the distribution on background, so its adaptive setting deserves further research. Furthermore the segmentation of different linear features is our current work, especially the extraction of contour lines. There are many gaps in the lines which are segmented by the methods based on pixels, thus reducing the efficiency and accuracy of the vectorization. So a clustering method based on line segments is used to segment different linear features, and the preliminary results have obtained, much better than that obtained by the method based on pixels. However, the optimal separated lines acquired by our method are the preconditions for the segmentation of different linear features.

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Qiguang Miao received the M.Eng and Doctor degrees in computer science from Xidian University, Shaanxi, China.

He is currently a Professor with the School of Computer Science and Technology, Xidian University. His current research interests include intelligent image processing and multiscale geometric representations for images.

Pengfei Xu received the B.Sc. degree from the Department of Information System and Information Manage, Xidian University, Shaanxi, China, where he is currently pursuing the Doctorate degree in computer application technology.

His current research interests include intelligent image processing.

Tiange Liu received the BSc degree from the Department of mathematics, Xidian University, Shaanxi, China, where he is currently pursuing the Doctorate degree in computer application technology.

His current research interests include intelligent image processing.

Yun Yang received the Doctor degree from The PLA Information Engineering University, Zhengzhou, China.

He is currently a Senior Engineer with the Xi'an Research Institute of Surveying and Mapping, Shaanxi, China. Her current research interests include digital mapping and image process.

Junying Zhang received the Doctor degree from Xidian University, Shaanxi, China.

She is currently a Professor with the School of Computer Science and Technology, Xidian University. Her current research interests include image processing and pattern recognition.

Weisheng Li received the Doctor degree from Xidian University, Shaanxi, China.

He is currently a Professor with the College of Computer Science and Technology, Chongqing University of Posts and Telecommunications, Chongqing, China. His current research interests include intelligent information processing.