Directional Segmentation Based on Shear Transform and Shape Features for Road Centerlines Extraction from High Resolution Images

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Abstract. Accurate extraction of road networks from high resolution remote sensing images is a problem not satisfactorily solved by existing approaches, especially when the color of road is close to that of background. This paper studies a new road networks extraction from remote sensing images based on the shear transform, the directional segmentation, shape features and a skeletonization algorithm. The proposed method includes the following steps. Firstly, we combine shear transform with directional segmentation to get road regions. Secondly, road shape features filtering are used to extract reliable road segments. Finally, the road centerlines are extracted by a skeletonization algorithm. Road networks are then generated by post-processing. Experimental results show that this method is efficient in road centerlines extraction from remote sensing images.

Keywords: Road centerlines extraction · Shear transform · Directional segmentation · Shape features

1 Introduction

Roads are the backbone and essential modes of transportation, providing many different supports for human civilization. Road extraction plays a very important role in vehicle navigation system, urban planning, disaster management system and traffic management system. Due to the improvement of image resolution, the image has all sorts of detailed information to obtain very good reflection, but these details characteristics are interference for the extraction of road. Also, high-resolution satellite images have serious shadows, particularly in urban areas, which have an impact on road extraction, so the road extraction from high-resolution satellite images has a great scientific significance. In recent years, various road extraction algorithms have been proposed. A variety of road detection techniques[1]include knowledge based methods[2], mathematical morphology[3],[4], snakes[5]–[6], classification[7]–[10], differential geometry[11], region competition [12], active testing [13], perceptual grouping [14], and dynamic programming [15]. Mena [16] and Fortier et al. [17] provide extensive surveys of the literature on road extraction technique.

Although the above methods show a good performance in road extraction, it is difficult to get a satisfactory result [18], and we need do some further research.

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Chaudhuri et al. [19] proposed a semi-automatic road detection method. In this method there were only a small set of directions to be used to detect the road segment. Thus some road segments are not detected. In order to solve the above problem, we would like to develop an efficient algorithm. This paper proposes a method based on shear transform, the directional segmentation, shape features and a skeletonization algorithm.

The organization of this paper is as follows: In Section 2, the new method is described. In Section 3, we compare the experimental result with a semi-automatic road detection method, and show that the method we proposed is efficient. Finally, the concluding remarks are given in Section 4.

2 Methodology

In this section, we first combine shear transform with directional segmentation to get road regions. Then, the road regions are refined by using shape features. Finally, we extract the road centerlines and make post-processing to get complete networks. Fig. 1 gives a summary of the proposed method.

2.1 Image Preprocessing and Directional Segmentation Based On Shear Transform

Image preprocessing consists of image enhancement and gray processing. In our implementation, Grey level transformation is used to adjust the contrast of details in an image. When we convert a color image to a gray image, some useful information will be lost. Therefore we apply grey level transformation on the color images.

Roads are mostly narrow and linear in the image. When we consider a small set of directions in the process of segmentation, some road segments are lost and we can't extract the whole complete road regions. However, looking for pixels in all directions can be computationally complex. Therefore the shear transform [20-25] is introduced here.

Let $W_{s,k}$ denote the multi-direction shear operation, where $s = 0$ or 1, $k \in [-2^{(ndir)}, 2^{(ndir)}], k \in Z$, Z denotes the set of integers and $ndir$ is the direction parameter $(ndir \in N)$. $s = 0$ means the shear transform is applied in the horizontal direction, and $s = 1$ in the vertical direction. By taking the multi-direction shear transform on the image $f(x, y)$, the sheared images $f'_{s,k}(x, y)$ would be obtained, the number of which is $2\times(2^{(ndir+1)}+1)$, as shown in equation (1)

$$f'_{s,k}(x, y) = f(x, y) * W_{s,k} \tag{1}$$

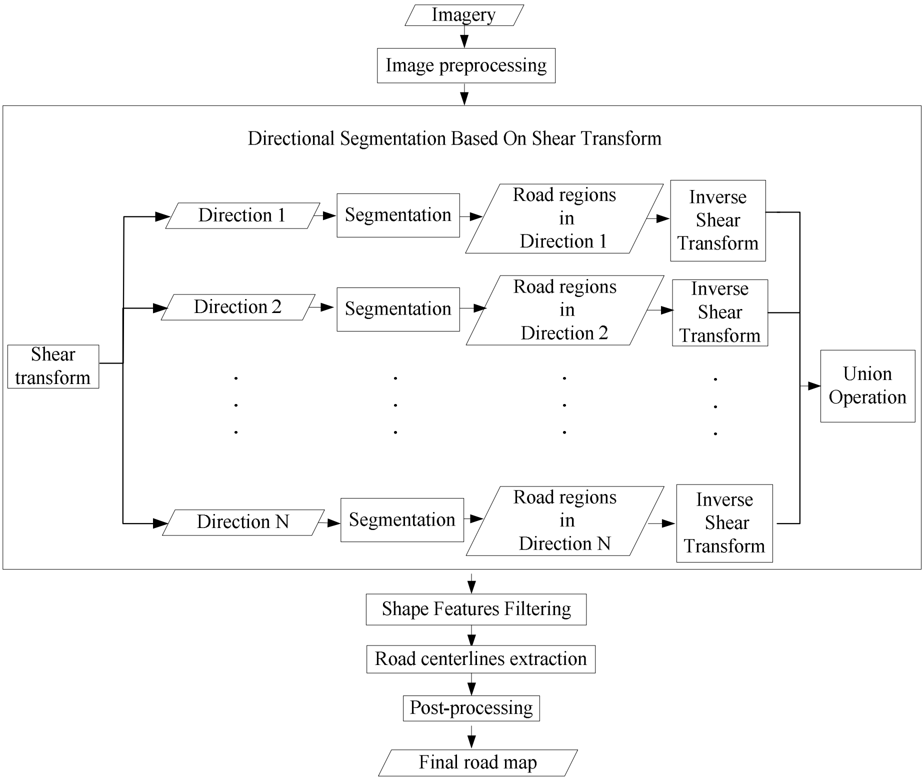


Fig. 1. Framework of the proposed method

In our implementation, shear matrix is $s_0 = \begin{bmatrix} 1 & 0 \\ \frac{\lfloor k \rfloor}{2^{ndir}} & 1 \end{bmatrix}$ or $s_1 = \begin{bmatrix} 1 & \frac{\lfloor k \rfloor}{2^{ndir}} \\ 0 & 1 \end{bmatrix}$.If $s = 0$ we take the shear transform according to the shear matrix s_0.

$$\left(x', y'\right) = \left(x, y\right) s_0 = \left(x, y\right) \begin{bmatrix} 1 & 0 \\ \frac{\lfloor k \rfloor}{2^{ndir}} & 1 \end{bmatrix} = \left(x + y \times \frac{\lfloor k \rfloor}{2^{ndir}}, y\right) \tag{2}$$

$$f'_{0,k}\left(x', y'\right) = f\left(x, y\right) \tag{3}$$

where $\left(x', y'\right)$ is the coordinate of a pixel in the sheared image and $\left(x, y\right)$ is 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.

A variety of sheared images which are obtained by the shear transform are shown in Fig. 2. The shear transform is applied to the image after preprocessing. Here we set $s = 0$ and $ndir = 2$, so the number of the sheared images is nine. It can be seen that the shear transform changes the entire neighborhood centered at a point and more directions for elongated regions will be estimated.

The algorithm to efficiently separate road segments in the sheared images is based on supervised directional homogeneity using a modified metric [19]. Two 5×5 road seed templates from the sheared images are chosen as the representatives. Considering only eight directions provides a good balance between computational efficiency and accurate extraction of road pixels, so we consider eight directions in every sheared image in this paper.

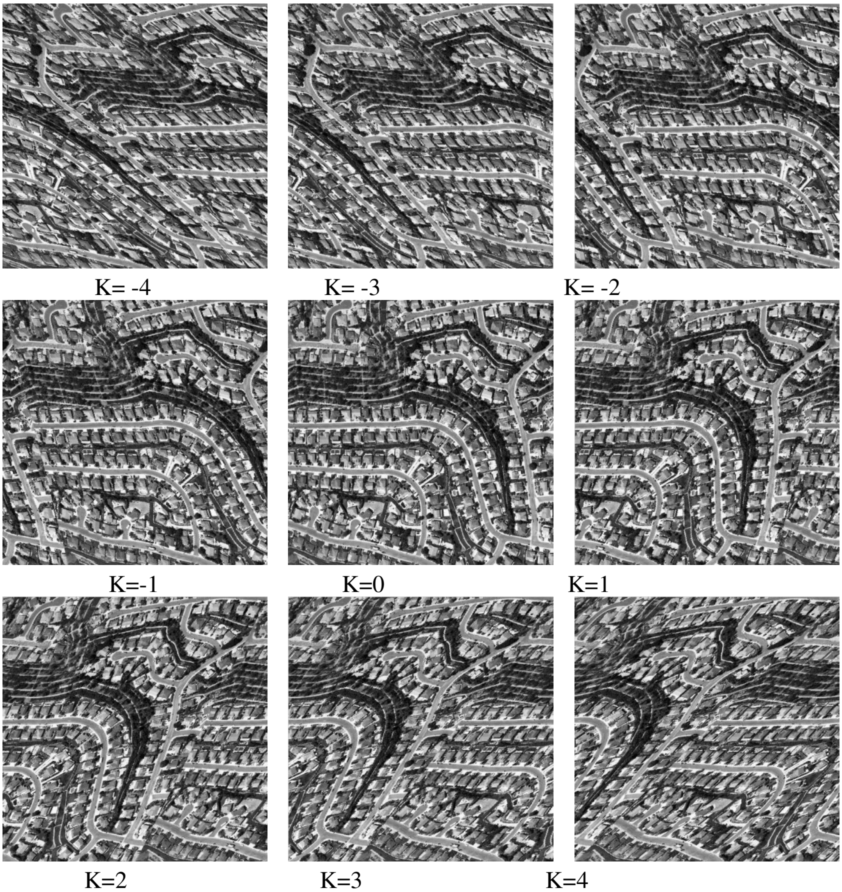


Fig. 2. Results of the shear transform

The inverse shear transform [20-25] is used for the images containing road segments in various directions, and then all of the images are fused into the final image by the union operation.

2.2 Shape Features Filtering

Some road regions identified after segmentation have some misclassified roads. To further discard misclassified roads, road shape features [26] are explored. These features are measured by the following: 1) area; 2) linear feature index (LFI).

1. Area: A road is commonly a continuous feature with a relatively larger area than other man-made features. Hence, segments with small area values can be regarded as noisy and should be removed.
2. LFI : Roads are generally narrower and longer than other artificial objects. This characteristic is described by LFI which is computed as follows.

- Using connected component analysis to divide pixels into connected components. The component is then converted to a rectangle which satisfies

$$LW = n_p \tag{4}$$

where L is the length of the new rectangle, W is the width of the new rectangle, n_p is the area of the road segment(also known as pixel number).

- LFI can be calculated by

$$LFI = \frac{L}{W} = \frac{L}{n_p / L} = \frac{L^2}{n_p} \tag{5}$$

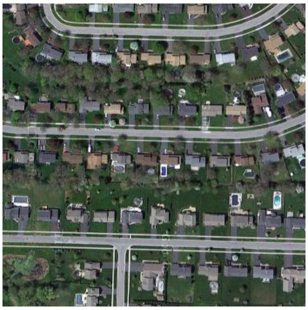
In terms of roads' characteristics, they should have large values of LFI, so regions with small values of LFI can be regarded as nonlinear features and will be removed.

2.3 Road Centerlines Extraction and Post-processing

In our implementation, we have used a well-known skeletonization algorithm proposed by Uitert and Bitter [27]. We then remove two kinds of unwanted linear segments to improve the linear representation of the roads in the image. The branches which are connected to the main road skeleton at one end and are not connected at the other end in the thinned image need to be eliminated, so we remove the branches whose length is less than the minimum threshold. The long linear structures that are isolated need also to be eliminated. We make these post-processing based on the filtering method proposed in [19].

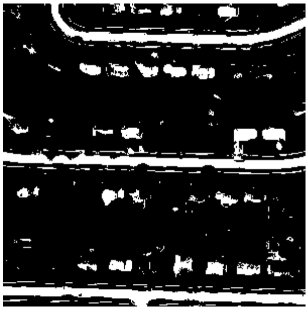
3 Experiments and Discussions

In this section, to test the performance of the proposed method we experiment with high-resolution aerial and satellite images and achieve satisfactory results. The proposed method is also compared with other's method to show the advantages and disadvantages of the proposed method. Fig. 3(a) shows a high resolution aerial image with spatial dimension of 300×300 pixels. The gray image is shown in Fig. 3(b). Fig. 3(c) shows the image after segmentation. As can be seen that road segments are mostly extracted. However, there are some small areas and noise in the segmented regions, which is convenient to remove in the following steps. Fig. 3(d) shows the image after shape features filtering. The final road networks result is shown in Fig. 3(e). In this experiment, all of the parameters and thresholds are set by the trial and error method in order to get a better result.

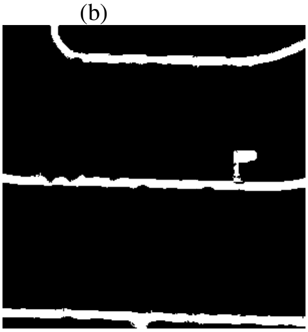


(a)

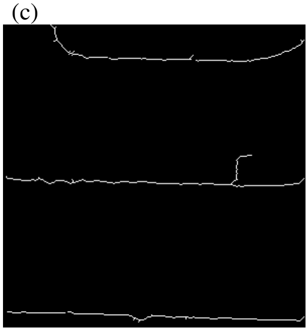
(b)



(c)



(d)



(e)

Fig. 3. Result with aerial image. (a) Original image, (b) Gray image, (c) Segmented image, (d) Image after shape features filtering, (e) Road networks.

(a) (b) (c)

Fig. 4. Comparison with Chaudhuri's method [13] on QuickBird image. (a)Input image, (b) Result of the Chaudhuri's method [13], (c) Result of the proposed method.

In order to prove the validity of the proposed algorithm, we compare our result with the method proposed by Chaudhuri et al. [19].As can be seen from the images shown in Fig. 4, the roads extracted by our algorithm are more complete and smooth than that generated by Chaudhuri's method. Clearly, most of the main road center-lines are extracted by the proposed algorithm.

We can conclude that the proposed method can perform more effectively than the other method. The computational complexity of the proposed method is higher than that of Chaudhuri's method, and it varies directly with the number of directions of the sheared images.

4 Conclusion

In this paper, we have presented a method to extract road centerlines from high-resolution images accurately and smoothly. The main steps in our algorithm are: image preprocessing, shear transform, road segmentation, shape features filling, road centerlines extraction and networks generation. In this method, the shear transform is introduced to overcome the limitation of directions for road segments. The experimental results have been evaluated to demonstrate the high accuracy of the proposed method. The extracted road centerlines retain smooth. However, the proposed method still has several flaws which we need to do some more research later. The main limitation of the proposed method is that all of the parameters and thresholds are set by the trial and error method, namely, be determined manually.

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