Automatic Extraction of Power Lines From Aerial Images

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***Abstract*—There has been little investigation for the automatic extraction of power lines from aerial images due to the low resolution of aerial images in the past decades. With increasing aerial photogrammetric technology and sensor technology, it is possible for photogrammetrists to monitor the status of power lines. This letter analyzes the property of imaged power lines and presents an algorithm to automatically extract the power line from aerial images acquired by an aerial digital camera onboard a helicopter. This algorithm first uses a Radon transform to extract line segments of the power line, then uses the grouping method to link each segment, and finally applies the Kalman filter technology to connect the segments into an entire line. We compared our algorithm with the line mask detector method and the ratio line detector, and evaluated their performances. The experimental results demonstrated that our algorithm can successfully extract the power lines from aerial images regardless of background complexity. This presented method has successfully been applied in China National 863 project for power line surveillance, 3-D reconstruction, and modeling.**

***Index Terms*—Aerial image, feature extraction, image processing, power line monitoring, power lines.**

I. Introduction

TRADITIONALLY, the aerial photogrammetric technique is not suited for power lines survey because the power lines in aerial images are too small to be detected [1]. Although the recent airborne laser scanning system is being applied in power line corridor monitoring, not all small private companies can afford such a cost. With increasing resolution of the aerial digital camera, it is possible for photogrammetrists to use the existing photogrammetric technique to periodically inspect the status of power lines. To this end, a joint research group between the State Key Laboratory of Remote Sensing Science and the Laboratory of Pattern Recognition and Intelligent System in Beijing University of Posts and Telecommunications was developing a multiangle imaging system for monitoring power line. The flight mission design such as flight height, imagery resolution, etc., is required to assure that the ground sample distance is higher than 0.05 m and the power line is imaged with at least one pixel width. A detailed description for the project can be found in [13].

This letter presents the research results of power line extraction from aerial images acquired from a helicopter. Related research has been made by a few authors. For example, Melzer and Briese [7] projected a group of parallel power lines (corridors) described by 3-D laser point cloud onto the x–y plane using a 2-D Hough transform and then locally fitted each 3-D power line within its corresponding corridor. Sarabandi and Park [9] and Kim and Kang [5] used a number of low-grazing incidence polarimetric synthetic aperture radar images to detect the power line. The detection criteria are based on clutter backscattering coefficients, power line size, and aspect angle with respect to radar. Yamamoto and Yamada [12] applied an infrared (IR) camera and a color video camera to record power lines. Their fusion is conducted to generate a virtually enhanced image for detecting and identifying the power lines. Blazquez [3] detected high-voltage power lines using IR imagery with consideration of the noise caused by background thermal patterns such as clouds and tall trees.

It has been demonstrated over the past decades that the automatic extraction of power lines from aerial imagery with a clutter background is a rather challenging task. There are few investigators to develop the algorithm for this purpose due to the fact that the early aerial images had a very low resolution so that the power line cannot be recognized. This letter presents the method for power line extraction from aerial images acquired from an aerial digital camera onboard a helicopter.

II. Power Line Extraction Method

The power line in the aerial image has the following properties.

- Power lines are a "linear" object, so they are close to a straight line, i.e., with a very small curvature on the aerial image.
- The topology of power lines is simple, i.e., they are continuous with 1-D extension between two power towers.
- Power lines are approximately parallel to each other.
- The power line is made of a special metal and thus has a uniform brightness on aerial images.
- There is no occlusion over the power lines, and the background is a natural landscape.

The above characteristics indicate that the power line aerial image is a linear object; thus, the following method is proposed.

A. Power Line Pixel Detection

1) Line Detector Mask: The line detector masks presented in [4] for linear feature extraction are depicted in Fig. 1(a).

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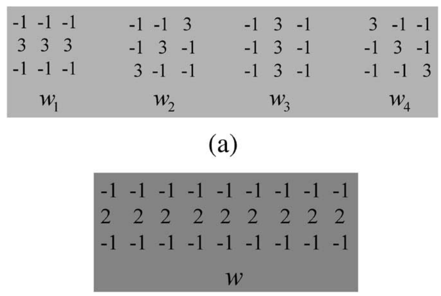

Fig. 1. (a) Horizontal line detector mask. (b) Line detector masks.

The mask orientations vary at the angles of 0°, 45°, 90°, and 135°. When the masks are convolved with a moving window, the strongest response is taken as the power lines, and the corresponding orientation is taken as the direction of a power line. In photogrammetric mission planning, the direction of flight is usually along the power lines, which results in the imaged power lines being approximately parallel to the margin of the image plane. Thus, the mask w_1 is adopted but extended into mask w to constrain the noise [Fig. 1(b)].

The above mask can be mathematically expressed by

$$W = \left(w(-4,-1),(-3,-1),\ldots,w(4,1)\right). \qquad (1)$$

With the above mask, the output gray value through convolution computation is

$$g(m,n) = \sum_{i=-1}^{1}\sum_{j=-4}^{4} f(m+i,n+j)\times w(i,j) \qquad (2)$$

where $f(m,n)$ is the gray value of the original image. With the convolution computation, the gray value of the power line is enhanced, and the background noise is refrained efficiently. Thus, the candidate pixels of power lines can be extracted.

2) Ratio Line Detector: Tupin *et al.* [11] applied the ratio edge detector that was first presented by Touzi *et al.* [10] for linear object extraction. This letter slightly modifies this algorithm as follows.

Let the amplitude of pixel s be denoted A_s. The radiometric empirical mean μ_i of a given region i having n_i pixels is $\mu_i = 1/n_i \sum_{s\in i} A_s$. The response of the edge detector between regions i and j is (Fig. 2)

$$r_{ij} = 1 - \min(\mu_i/\mu_j, \mu_j/\mu_i). \qquad (3)$$

Because an imaged power line is 1-D, the response of the line detector is

$$r = \min(r_{21}, r_{23}) \qquad (4)$$

where subscripts 1, 2, and 3 denote the central region and the two lateral regions (Fig. 2). If a pixel's response r is large enough, i.e., higher than a prior given threshold $r_{\min}$, it would be considered as a line object. For the 550-kV power lines in our project, the material usually has a lower reflectance than its surrounding background. So we add the constrain condition by

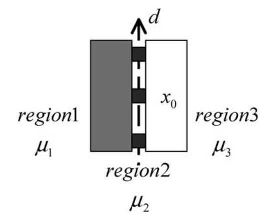

Fig. 2. Vertical line model by ratio edge detection.

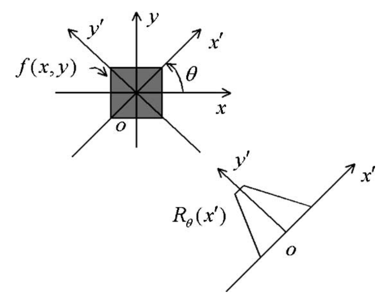

Fig. 3. Geometry of Radon transform.

$$\mu_2 < \mu_1 \qquad \mu_2 < \mu_3. \qquad (5)$$

If (5) is satisfied, the pixel is extracted and taken as one of the power line pixels.

Comparing the two operators, we think that the two operators are effective for linear object extraction with a strong antinoise capability. Especially, both are capable of detecting the line object of one pixel wide from a complex natural background. On the other hand, the line mask detector produces noise if the contrast of the edge is large, but meanwhile, it enhances the image edges of the linear object. The ratio line detector can detect the line objects more efficiently than the line mask detector; but usually, a prior experimental threshold has to be set up.

B. Line Segments Detecting and Grouping

After the power line pixels are detected above, the following task is to trace candidate lines and describe the line segments using a vector form, and then group them. So the following two steps are conducted.

1) Radon Transform: Fig. 3 illustrates the geometry of the Radon transform [8], where the projection of a 2-D function $f(x,y)$ is considered as line integrals. The Radon function computes the line integrals from multiple sources along parallel paths in a certain direction. The projection is computed along any angle θ. In general, the Radon transform is the line integral of $f(x,y)$ parallel to the y' axis, i.e.,

$$R_\theta(x') = \int_{+\infty}^{-\infty} f(x'\cos\theta - y'\sin\theta, x'\sin\theta + y'\cos\theta)dy' \qquad (6)$$

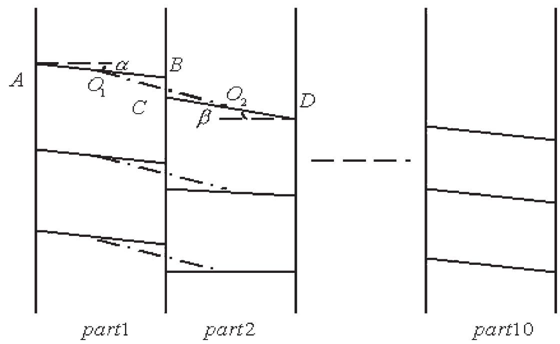

Fig. 4. Line segment grouping procedure.

where

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}.$$

With the Radon transform function, a 2-D matrix is acquired with a row vector containing the corresponding coordinates along the x' axis and a column vector containing the Radon transform of the image for each angle.

2) Line Segment Grouping: After the power line pixels are detected above, an imaged power line is segmented into several sections along the approximate orientation of power lines. The segmented sections assure that each line segment is a straight line. Based on this, the following criteria describe how to group the line segments from neighbor sections:

1) The slops of line segments in the neighbor parts meet the condition of the $|\alpha - \beta| \leq$ angle threshold.
2) The distance of the endpoints of a line should meet the condition of the $BC \leq$ distance threshold.

The symbols in the above two conditions are illustrated in Fig. 4. When they are met, a line is fitted using the middle points, i.e.,

$$AD = AO_1 + O_1O_2 + O_2B. \tag{7}$$

Repeat the same operation for each section until all sections are finished. After this step, most of the line fragments are smoothly connected, and a few gaps (break off) in the lines will be handled using the Kalman filter algorithm to be described below.

C. Kalman Filter to Track Line

The above processing unavoidably causes the gaps in the line. The Kalman filter algorithm is employed to track the broken-off power lines for filling them out. The method is that each line is considered as a track of a moving point on a straight line. When the broken-off line fragments are not detected, the Kalman filter is employed to track the broken-off next section. If there are line segments that meet the two conditions in Section II-B2, they will be connected. The operation for tracking line fragments starts from the middle of a long line segment and moves up and down. When a broken-off line is encountered, a number of the broken-off pixels along the tracking direction are preassigned. The assigned number is required to assure that the method can effectively track the next section. Thus, the two neighbor pixels are detected, and the detected line segments are connected. This computational process is mathematically described as follows. If we track a line along the horizontal orientation, let $X(k)$ be the state vector of movement, $x(k)$ be the moving location, $x'(k)$ be the velocity, $y(k)$ be the observation location, which is the location of the detected line point, T be the step size, and k be the tracing time. The state equation of constant velocity of point D is

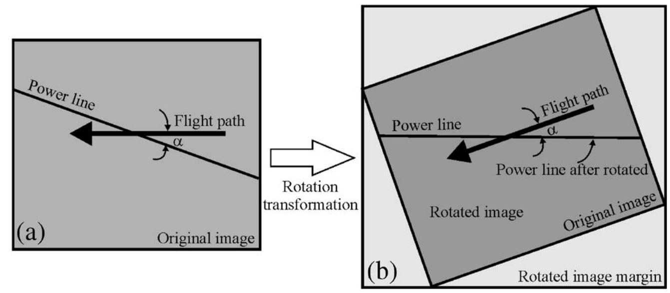

Fig. 5. Flight path deviation from power lines.

$$X\left((k+1)/k\right) = AX(k) \tag{8}$$

where

$$X = \begin{bmatrix} x \\ x' \end{bmatrix} \quad A = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}.$$

The measurement model is simplified as

$$Y(k) = CX^T(k) \tag{9}$$

where $C = [1 \quad 0]^T$, and $Y(k) = [y \quad y']^T$. The predicated state equation is

$$\hat{X}\left((k+1)/k\right) = A\hat{X}(k). \tag{10}$$

The output of the filter is

$$\begin{aligned} &\hat{X}(k+1) = \hat{X}\left((k+1)/k\right) + K(k+1) \\ &\Big(Y(k+1) - C\hat{X}\left((k+1)/k\right)\Big) = \hat{X}\left((k+1)/k\right). \end{aligned} \tag{11}$$

After the Kalman filter is carried out, an entire power line is extracted.

D. Other Cases

The above developed detector only considers the case where the flight path is approximately parallel to the power lines. If the flight path deviates from the power line at an angle of α [Fig. 5(a)], an image rotation transformation is employed so that the margin of the rotated image is "parallel" to the power line [Fig. 5(b)]. This work is implemented manually. However, the computation load is increased because the dimension of the rotated image becomes bigger than that of the original image [Fig. 5(b)].

III. Experimental Results and Analysis

A. Experimental Results

The first experimental field is located in Xiangfan, Hubei, China. The aerial images for high-voltage transmission power

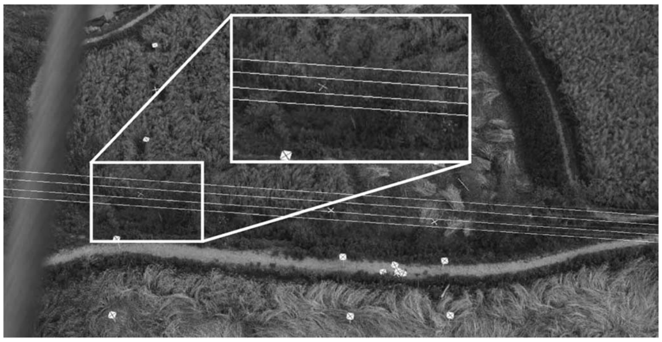

Fig. 6. Original image with four power lines, which is magnified in the subwindow.

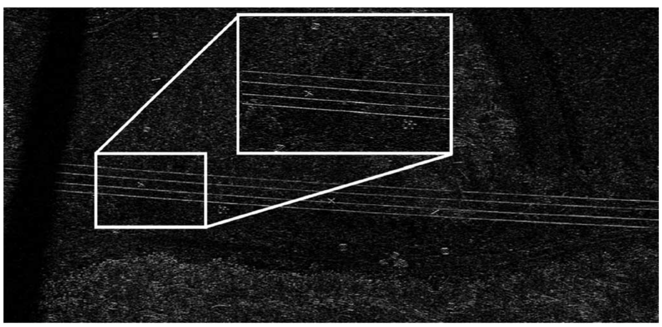

Fig. 7. Detected results using the line mask.

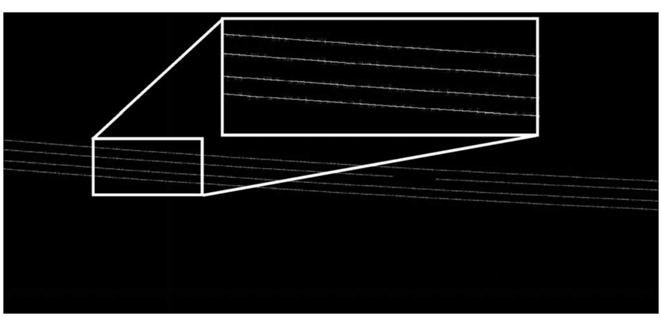

Fig. 8. Detected results using Radon transform and line grouping.

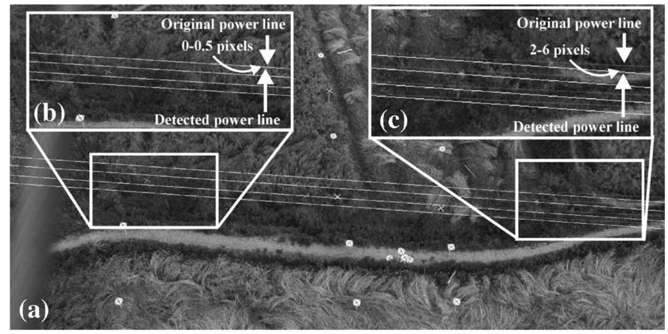

Fig. 9. Final extracted power lines (bright lines), which are superimposed on the original images.

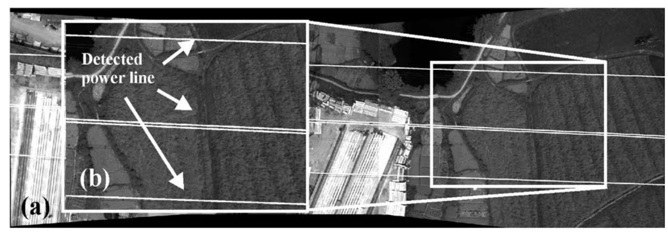

Fig. 10. Experimental results using the developed method in another scene.

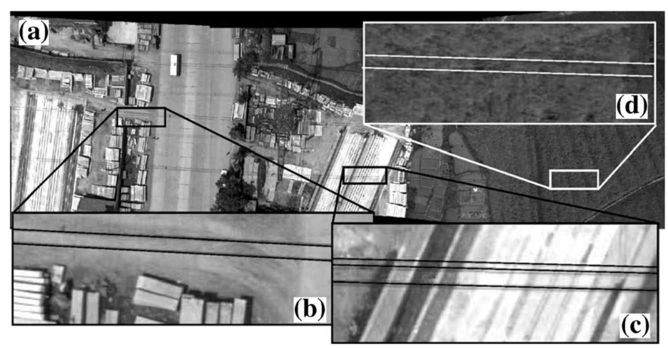

Fig. 11. Evaluation of the proposed method in the suburban area.

lines of about 35 m high were acquired in March, 2005, using a Kodak Pro 760 camera onboard a helicopter. Fig. 6 is part of one original aerial image in which the power line with one pixel wide was captured and the background is clutter natural landscape, mainly trees and bushes. Another experiment was in Jiangxia, Hubei, in May, 2005. Three-view charge-coupled device (CCD) cameras are used to acquire images. The resolution is 1600×1200 pixel^2. The altitude of the helicopter and the height of four 550-kV transmission power lines are about 150 and 50 m over the ground, respectively. Each power line is imaged at over one pixel wide. The proposed method is evaluated using the two data sets, and some results are given as follows (Figs. 7 and 8).

From Fig. 9(b), it has been demonstrated that the developed approach can exactly extract the power lines automatically. When we superimpose the extracted power lines onto the original images, as depicted in Fig. 9(b) and (c), the minimum position difference is 0.5 pixel, but the maximum one reaches five to six pixels. We analyzed the causes. This is because the algorithm took an entire power line as a straight line, while the true power line has a slight curvature. For this reason, we divide an entire power line into many sections so that each power line section is an approximate straight line. For example, the power lines in Fig. 10 are divided into ten sections when conducting the Radon transform. After the Radon transform is carried out, the power lines are extracted. With the Kalman filter, the gap of two neighbor end-to-end lines is filled, and an entire power line is extracted. To further validate the effectiveness of our method, we tested another scene (Fig. 10).

We also tested the proposed methods in the other two areas: one is in a suburban area, where the background is very complex; the other one is in a rural area, where the background brightness is big. The tested results, as depicted in Figs. 11 and 12, demonstrated that the proposed method also has a good result in the two areas.

B. Discussion

In the beginning of the project, a traditional Hough transform to test the power line extraction was applied. We found that the background linear features, e.g., roads and house edges, are

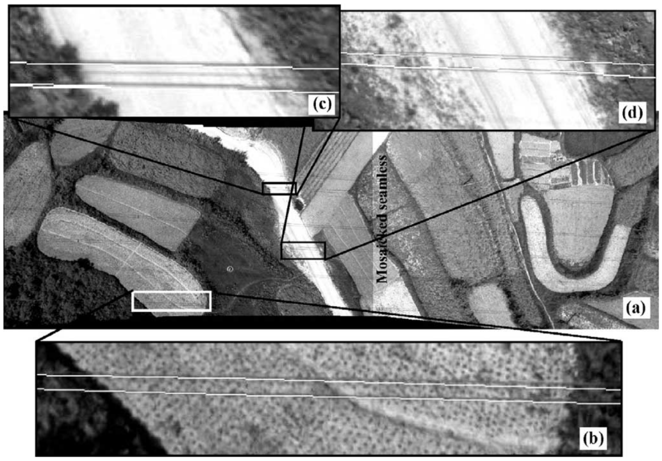

Fig. 12. Evaluation of the proposed method with big brightness background.

TABLE I
STATISTICAL ANALYSIS OF THE ALGORITHM

	Total Length	Extracted length	
		by algorithm	by interaction
Test area 1	13.2km	12.1km	1.1km
Test area 2	9.3km	8.5km	0.8km

extracted. As a result, the workload for the postprocessing of the power line extraction is big because the imaged power lines only contain one pixel wide. Moreover, the Hough transform is time consuming and needs a large storage space. We also tested the Duda Road Operators [2], and the results show that this operator largely depends on the gray difference between power lines and background [6]. Moreover, the computation loads are very much because it needs convolution calculation. The comparison analysis, discussion, and experimental results can be found in [6]. Relatively, the Radon transform is simple and consumes less time, although it cannot locate the starting and ending points of a line. Nevertheless, this shortcoming can be disregarded because a power line is usually through an entire image.

Additionally, we statistically analyzed the successful rate of automatic extraction of the power lines. The results show that over 90% of total power line length can automatically be extracted and less than 10% of the total power line length is extracted by human–computer interaction. The extracted power lines are finally compiled manually into a vector data (Table I).

IV. CONCLUSION

In this letter, a method of extracting the power lines from aerial images is presented. This proposed method considers the properties of power line imaging such as linear, parallel of two power lines, homogenous gray, etc. The antinoise linear detection operator is designed to detect the pixels of the power line. Section II-B1 is employed to extract and group the line segments for forming a straight line. The Kalman filter method is applied to connect the gap of two lines. The experimental results demonstrated that the developed methods are capable of successfully identifying the power lines.

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