Edge detection of foreign matter suspension image of high voltage transmission line based on improved Canny operator

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Abstract—In the edge detection of foreign object hanging image of high voltage transmission line, it is easy to appear that multiple responses will appear at one image edge point, which affects the detection effect. Based on the improved Canny operator, an edge detection method for foreign matter suspension image of high voltage transmission line is designed. The collected image is preprocessed in three steps: gray processing, optical correction and noise reduction, so as to better reflect the characteristics of the original image and improve the image quality. The non-uniform distribution of potential energy of foreign body hanging image data field is used to locate the image area of foreign body hanging. The morphological filter can extract the local noise and make the image clearer. The Canny operator is improved to obtain the partial derivative of the distance measurement function and automatically update the threshold to eliminate the multi-level response. The test results show that the method in this paper is better than the image edge detection method based on Canny operator and Sobel operator in three indexes: positive detection rate, false detection rate and missed detection rate.

1. Introduction

Transmission lines connect power plants and consumers, and play an irreplaceable role in the process of power transmission. At the same time, due to the large north-south latitude and complex conditions, the wires need to be exposed to ice and snow weather or hot and humid weather for a long time. Transmission lines in different environments suffer from different degrees of damage caused by lightning, bird damage, wind damage, tree discharge, construction damage, etc. Therefore, it is very important to find and solve the abnormalities in the transmission line in time, grasp the operation situation in real time through remote monitoring equipment, and ensure the smooth operation of the transmission line [1]. The anomaly detection algorithm of transmission line can effectively detect the anomalies of transmission line, such as foreign body attachment, falling bird, broken strand bifurcation, so as to save the labor and material cost of daily inspection of transmission line. Manual patrol inspection mainly relies on optical equipment, which requires a lot of manpower and material costs, low detection accuracy and potential safety hazards of missing detection. In recent years, with the rapid expansion of transmission network system, manual inspection has withdrawn from the stage of history because of its low efficiency and high cost. Later, aircraft patrol inspection and robot patrol inspection were introduced from abroad, which were based on camera to collect transmission line images, and then rely on manual screening to diagnose the operation of transmission lines.

The foreign matter hanging of transmission line is a common hidden danger and an important cause of transmission line failure. The abnormalities and hidden dangers of transmission line should be found early and eliminated in time [2]. Foreign matters and falling birds hanging on the transmission
line will shorten the electrical safety distance between transmission conductors. In extreme cases, the attachment of foreign matters will lead to mutual discharge of transmission lines, resulting in a large-scale major power outage. Therefore, it is very necessary to use intelligent analysis based on image processing of transmission lines. Therefore, based on the improved Canny operator, this paper designs an edge detection method, which can accurately judge the abnormal conditions such as foreign body attachment of transmission line and make a quick judgment, which provides a new scheme for on-line abnormal monitoring of transmission line.

2. Edge detection of foreign object suspension image based on improved Canny operator

2.1. Image preprocessing of foreign matter hanging on high voltage transmission line

In order to better reflect the original characteristics of the image, it is necessary to preprocess the image. Preprocessing generally includes three steps: image graying processing, image enhancement processing and image restoration processing [3]. After this series of operations, the image quality will be greatly improved, which lays a foundation for the recognition and extraction of high-voltage transmission lines from the image. The images taken in the cruise phase of transmission line are generally saved as color images in JPG format. In order to facilitate the call of image processing function, the image needs to be grayed [4]. The R, G and B components in the color image are weighted by adding different weight coefficients before the three components according to their attributes and features. The final obtained value is used as the gray value. The method can be expressed by formula (1).

\[ D(a,b) = \varphi_1 R(a,b) + \varphi_2 G(a,b) + \varphi_3 B(a,b) \]  

In formula (1), \( D(a,b) \) represents the gray value; \( (a,b) \) represents pixel coordinates; \( R, G \) and \( B \) represent three components; \( \varphi_1, \varphi_2 \) and \( \varphi_3 \) represent the weight coefficients of each component. The sum of the three weight coefficients is 1. By adjusting the weight parameters, a reasonable gray image is obtained. In the cruise shooting stage, due to the influence of flight attitude, camera angle or light intensity, the collected images will have problems such as uneven brightness distribution or reduced image contrast [5]. Adaptive histogram equalization can be expressed by equation (2).

\[ D'(a,b) = \begin{cases} f(a,b) + \alpha [D(a,b) - \beta], 0 < D(a,b) < 255 \\ f[D(a,b)], otherwise \end{cases} \]  

In formula (2), \( D'(a,b) \) represents the gray value after optical correction; \( f \) represents the mapping function. In this paper, the cumulative distribution function is selected for calculation. \( \alpha \) represents the number of pixels; \( \beta \) represents the average gray value of the window. The image quality will be degraded due to the mixing of noise. This phenomenon is called image degradation. The process of noise contained in the image to improve quality is called restoration. Through the analysis of aerial images, it is found that Gaussian noise is the main factor causing image degradation [6]. With the increase of the distance from the template to the center, the corresponding weight will gradually decrease. The zero mean discrete Gaussian function is used for image processing, and the calculation formula is as follows:

\[ D''(a,b) = \gamma e^{\frac{(a^2 + b^2)}{2\delta^2}} \]  

In formula (3), \( D''(a,b) \) represents the gray value after noise reduction; \( \gamma \) is the normalization coefficient; \( e \) is the natural constant; \( \delta \) indicates the width parameter. Through the above operations on the image, the image quality can be improved, which lays a foundation for the extraction of foreign matters in the transmission line.
2.2. Positioning of suspended foreign matters

After image preprocessing, the primary task is to recognize and extract the target from the image. In many cases, foreign objects and transmission lines are confused in the same connection domain. In addition, due to the different angles of image acquisition, the direction of the target in the image will be very different. Moreover, there are many kinds and shapes of foreign bodies, and it is difficult to distinguish them by comparing with the shape characteristics of known targets [7]. It is assumed that the final distribution area is a rectangular area, and the length and width of the rectangle are parallel to the image boundary. Starting from the $3 \times 3$ neighborhood centered on the global maximum of data field potential energy, expand the width of one pixel outward from the top, bottom, left and right directions each time. When the foreign area is expanded along a certain direction, the sum of the internal data field before and after remains unchanged [8]. The termination conditions of this area are as follows:

$$
L_1 = \frac{X_1 + X_2}{4} \\
L_2 = 3
$$

In formula (4), $L_1$ means that the number of cycles reaches the given upper limit; $L_2$ indicates that the cumulative number of zero growth in a certain direction reaches the upper limit; $X_1$ and $X_2$ represent the growth in the downward and right directions [9].

2.3. Morphological filtering for extracting hanging foreign matter image

Image edge extraction is mainly to measure the gray change, enhance the high-frequency component, and locate, detect and extract edge. When extracting the edge, it is difficult to obtain results by linear filtering method [10]. Therefore, the nonlinear filtering method must be used to obtain more real edge image information, but the nonlinear median filtering still misses the pulse noise with high density. Therefore, a nonlinear filtering algorithm based on mathematical morphology is presented. Its new algorithm has been frequently used in other modules of image processing. For example, edge detection, image enhancement, image tracking, pattern recognition and so on. The function of low hat operation is just opposite to that of high hat operation, which can eliminate the noise of dark matter on bright background. Therefore, the combination of high hat and low hat operators can make the background of the image more clearly separated from the target object and enhance the edge detail information of the image. The formula of multi structure composite anti noise morphological operator is as follows:

$$
\begin{align*}
\tilde{c}_1 &= Y - \left[ [Y\kappa_1] \bullet \kappa_2 \right] \kappa_1 \\
\tilde{c}_2 &= \left[ [Y\kappa_1] \bullet \kappa_2 \right] \kappa_1 - Y \\nY' &= \tilde{c}_1 - \tilde{c}_2 + Y
\end{align*}
$$

In formula (5), $\tilde{c}_1$ and $\tilde{c}_2$ represent the enhanced high hat operator and low hat operator; $Y$ and $Y'$ represent the original image and the edge image to be obtained; $\kappa_1$ and $\kappa_2$ represent cross and diamond matrix elements. Moreover, in the process of filtering, the noise points under the action of specific matrix elements can be permanently smoothed out without repetition, and the overall structure of the image can not be passivated.

2.4. Image edge detection algorithm based on improved Canny operator

Canny operator is a classical edge extraction algorithm in image edge extraction algorithm. Canny operator is actually the derivative of Gaussian function. It is an organic combination of image gradient operation and image Gaussian function smoothing. Although the first derivative of Gaussian function does not have rotational symmetry. However, the algorithm has the characteristics of symmetry in the image edge direction and antisymmetry along the gradient direction. This makes Canny operator not
only obtain good edge accurate positioning, but also have good anti noise performance in image edge extraction algorithm. The process of image edge extraction using Canny operator is shown in Figure 1.

The standard Canny operator uses Sobel operator to obtain the gradient amplitude in the neighborhood, but there are only 4 directions for the first derivative. To solve this problem, an 8-neighborhood calculation method is proposed, which not only solves the gradient value and azimuth in the direction of pixels, but also solves the gradient value and azimuth in the direction of 45° and 135°. The calculation formula of gradient value and azimuth at pixel points is as follows:

\[
\begin{align*}
\tau(a,b) &= \max \left( |\lambda(a,b)_x|, |\lambda(a,b)_y|, |\lambda(a,b)_{45}|, |\lambda(a,b)_{135}| \right) \\
\theta(a,b) &= \arctan \left( \frac{\lambda(a,b)_y}{\lambda(a,b)_x} \right)
\end{align*}
\]

In formula (6), \( \tau(a,b) \) represents the gradient value at the pixel point; \( \theta(a,b) \) represents azimuth; \( \lambda \) represents the filtered image. The standard Canny operator mainly sets the high and low threshold through human experience. At the same time, it can delete those pseudo edges with short edge length or weak image edge intensity. So far, the edge detection method of foreign object suspension image of high voltage transmission line based on improved Canny operator has been designed.

3. Experimental test

3.1. Data set

Based on the image sequence taken at fixed camera intervals, this paper carries out relevant experimental tests. In order to prove the effectiveness of the designed detection method, tens of thousands of sequences from multiple surveillance cameras are randomly selected. The data set is taken from the sequences collected by tens of thousands of high-voltage transmission line surveillance cameras in 17 cities of a province. In factories or construction sites, such scenes are prone to foreign matter intrusion. The last category is residential buildings or urban areas, which are the scenes with the most frequent human activities. According to statistics, the proportion of the above four scenarios in the test set is as follows:
Table 1 Proportion of monitoring scenes

| Scene category          | Quantity | Proportion (%) |
|-------------------------|----------|----------------|
| Field                   | 215      | 43             |
| Village                 | 115      | 23             |
| Construction site       | 105      | 21             |
| Residence community     | 65       | 13             |

As shown in Table 1, the proportion of field monitoring scenes is the highest, about 43%. The proportion of other types of scenarios is much lower than it, which is consistent with the distribution of actual transmission lines. 15658 images were randomly selected. The number of images of field, village, construction site and residential area is 10065, 1582, 1655 and 2356 respectively.

3.2. Test result

The edge detection of foreign object hanging image includes two processes: delimiting the area where the foreign object is located and determining whether the area contains foreign objects. Therefore, the accuracy of the whole process of the algorithm includes three indicators: positive detection rate, false detection rate and missed detection rate. The specific image of the input algorithm can be divided into two types, one is the image without foreign matter in the transmission line, and the other is the image with foreign matter in the transmission line. According to the correspondence relationship between the input image type and the judgment result output by the algorithm, it can be divided into positive detection, false detection and missed detection, as shown in Table 2.

| Input Output Result | Input | Output | Result           |
|---------------------|-------|--------|------------------|
| No foreign matter   | No foreign matter | Positive detection |
| Containing foreign matter | Containing foreign matter | Positive detection |
| No foreign matter   | Containing foreign matter | False detection    |
| Containing foreign matter | No foreign matter | Missed detection  |

In order to verify the effectiveness of this method, it is compared with the image edge detection method based on Canny operator and Sobel operator. Sobel operator is a first-order differential operator, which is obtained by calculating the gradient value of the pixel position in neighborhood. The test results of the test data set are shown in Table 3.

Table 3 Edge detection results of foreign matter hanging image

| Detection result | Field | Village | Construction site | Residence community |
|------------------|-------|---------|-------------------|---------------------|
| Positive detection rate (%) | Improved Canny operator | 95.62 | 96.31 | 94.06 | 95.17 |
|                   | Canny operator         | 90.08 | 89.23 | 90.62 | 91.85 |
|                   | Sobel operator         | 92.19 | 91.44 | 92.13 | 91.16 |
| False detection rate (%) | Improved Canny operator | 0.26 | 0.32 | 0.27 | 0.28 |
|                   | Canny operator         | 1.16 | 1.14 | 1.06 | 1.09 |
|                   | Sobel operator         | 1.08 | 0.96 | 0.98 | 1.02 |
| Missed detection rate (%) | Improved Canny operator | 3.42 | 3.56 | 3.14 | 3.07 |
|                   | Canny operator         | 4.92 | 5.03 | 4.98 | 5.16 |
|                   | Sobel operator         | 4.85 | 4.92 | 4.76 | 4.99 |
According to the test set detection results in Table 3, the method proposed in this paper can effectively detect the edge of foreign body hanging image. The average positive detection rate of this method is 95.29%, which is 4.84% and 3.56% higher than the detection method based on Canny operator and Sobel operator. The average false detection rate of this method is 0.28%, which is 0.83% and 0.73% lower than the detection method based on Canny operator and Sobel operator. The average missed detection rate of this method is 3.30%, which is 1.72% and 1.58% lower than the detection method based on Canny operator and Sobel operator. Based on the above results, this method can obtain the edge feature information of foreign body hanging pattern, and locate accurately. It has achieved good detection results in three indexes: positive detection rate, false detection rate and missed detection rate, and has good detection performance.

4. Conclusion

It proposes an edge detection method of foreign object hanging image of high voltage transmission line. The test results show that this method can accurately locate the foreign object hanging in the inspection image of transmission line, and has good detection performance. Due to the limitation of image shooting quality, the inspection images of high-voltage transmission lines used in this paper are long-range images, so the texture information of suspended foreign objects can not be used for target detection. When the number of samples is sufficient, the next step can combine the color, texture and other information to realize the foreign object detection on the high-voltage transmission line, or use the deep learning related algorithm to detect. At the same time, the anomaly detection algorithm in this paper can only detect the location, but does not distinguish the types of broken strands, falling birds and foreign objects. In the future research process, the identification of fault types and the types of suspended foreign objects can be increased. The change area is caused by human and non-human factors. When the two are mixed together, how to accurately segment the change area with hidden dangers is still an important problem.

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