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Identification and Fault Diagnosis of Insulators in the Unmanned Aerial Vehicle (UAV) Images

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Abstract: Aiming at the fault of spontaneous detonation and peeling of insulator of transmission line, studies are carried out in the aspects of the preprocessing of the insulator images, recognition of insulator, and fault diagnosis and the algorithm of insulator extraction and recognition is proposed under the complicated background because of the complex background of aerial image. After the primary optical rectification of the images, wavelet denoising algorithm based on edge detection and the improved Canny edge detection algorithm are used to detect the edge of the image, and the improved Hough transform is employed to detect the incomplete ellipse, thus classification decision method designed according to the ellipse parameter is applied to verify. Therefore, the results show that the method can obtain the ellipse parameters of the insulator string, and realize the functions of the edge detection, identification and fault diagnosis of the insulator in the aerial images.
Key words: insulator, wavelet denoising, image recognition, fault diagnosis.

1. INTRODUCTION

Electric power is an important energy artery for a country and the grid is the main carrier of electricity, hence maintaining the operation of the grid is a vital guarantee for the steady development of the national economy. With various advantages such as simple structure, easy construction, low cost, short construction period, convenient maintenance and low technical requirements, the overhead line has been widely employed. However, long-term exposure to the natural environment, the line equipment is susceptible to the invasion of various weather conditions (such as winds, snow, temperature changes, lightning, etc.), the corrosion of chemical gas and external damage, which has a higher probability of causing fault. The performance of insulators used in overhead lines and outdoor substations is a key factor in determining the reliability of power transmission systems. For the two widely used insulators in the transmission lines, porcelain insulators will be broken or even peeled in the mechanical, electrical and other effects, and glass insulators will be caused spontaneous detonation under the effect of natural environment, mechanical load, production process and other issues, which seriously affected the operation of the grid.

Although the method of insulator detection has achieved some achievements, most of them have complex operation, high cost, high risk, and poor anti-interference ability. In recent years, the method of insulator detection based on computer image-processing techniques has achieved greatly developed. This paper studies the identification and state detection of insulators on the basis of aerial images.

2. THE FLOW OF FAULT DIAGNOSIS OF INSULATOR

In order to observe the characteristics of insulators of the transmission lines clearly, this study distinguishes them from the environmental background, and then conducts preprocessing to the aerial images of insulators. Moreover, the captured colored images account for a large amount of storage space, and affect the calculation speed; in addition, the noise mixed during the shooting also need to be further processed. After threshold segmentation of the images, the appropriate methods are selected to implement edge detection for the obtained binary images, so as to gain the continuous clear outline.

According to the elliptical characteristics of insulators, the improved Hough transform is utilized to detect the incomplete ellipse in the edge image, and the parameter space is reduced to one dimension in order to realize the fast and accurate detection of ellipse. Finally, classification decision made according to the obtained ellipse parameters, accurate identification of the insulators and analysis whether the insulator is peeling in light of the statistical information of the insulators are well studied consequently.

The flow of fault diagnosis of insulator proposed in this study is shown in Fig. 1

3. IMAGE PREPROCESSING

3.1. Optical Rectification

In the process of image capture, the input-output characteristic of the imaging sensor is non-linearity, that is, the intensity of incident light L and the exposure amount D (or the output current I) exists the non-linear relationship. Therefore, there is no response in the particularly dark part due to the effect of inherent noise, no completely proportional relationship in the middle part, but the saturation phenomenon in the particularly bright part.

If f is the Grayscale of the image and L is the intensity of incident light of the CCD image sensor, then the relationship between the intensity of input light and the output signal can be expressed as:

$$\mathrm{f} = \mathrm{c}L^{\gamma} \tag{1}$$

Where c is a constant.

If γ = 1, then f and L are the proportional relationship; usually the number of CCD sensor γ is from 0.4 to 0.8, appearing a nonlinear relationship. The exposure time is generally fixed in the shooting, but underexposure or excessive exposure may appear due to changes of lighting conditions, thus causing the image too dark or too bright. Therefore, optical rectification is primarily needed for the aerial image.

According to $f = cL^{\gamma}$, the Grayscale of the image has a nonlinear relationship with the actual light intensity. In order to rectify the nonlinear to linear relationship, nonlinear transformation must be conducted. The constructed nonlinear transformation is as follow:

$$g = KL = k\left(\frac{f}{v}\right)^{\frac{1}{\gamma}} \tag{2}$$

Where g is the Grayscale of the transformed image; k is the constant, usually as 1. This method is also called Gamma correction. Setting a Grayscale image with the resolution of m × n, g¯ is its average Grayscale feature.

$$\bar{g} = \frac{1}{m * n}\sum_{i=1}^{n}\sum_{j=1}^{m} f(i,j) \tag{3}$$

F (i, j) is the value of Grayscale at point (i, j). Since the total Grayscale feature of an image is mainly determined by the Grayscale of the background, and the size of the background Grayscale determines the size of the average Grayscale $\bar{g}$, so the average Grayscale $\bar{g}$ can be used as a Grayscale feature of an image. A transformation table is constructed by experiment in accordance with the average Grayscale, introducing the relationship between the average Grayscale $\bar{g}$ and the γ value.

If the pixels of an image occupy all the possible gray levels and distribute evenly, the image has a high contrast and variable gray tone, thus showing the images with abundant gray levels and large dynamic ranges. The idea of histogram equalization is to transform the uneven distribution of the histogram to the even form, which increases the dynamic range of the Grayscale value and achieves the effect of enhancing the overall contrast of the image.

3.2. Image recovery

All kinds of noise have their own different characteristics, it is difficult to use a single de-noising algorithm to remove. The traditional method is to denoise through a low-pass filter, filter out the frequency of noise components in the signal, but the details of the image part of the production damage; and for salt and pepper signal, white noise, non-stationary process signal, the traditional method there is a limit In the case of low signal to noise ratio, after filtering, not only the signal to noise ratio is not improved, and the position information of the signal is also blurred. So, choose a good versatility, you can remove a variety of noise algorithm is very important. The denoising method of wavelet transform based on Canny edge detection is such an effective method.

According to the method of image edge detection, the image edge information is detected, and the edge information is stored.

The multi-scale wavelet transforms of the image f (x, y) is carried out to obtain the wavelet coefficients of the horizontal, vertical and diagonal high frequency components of each layer. The number of decomposed layers is generally 3.

The standard deviation of the noise is estimated for the high frequency coefficients. let σˆ= MAD/0.6745.

The threshold T of each layer is calculated according to the formula T = σ2ln N /ln(j+1).

According to the formula, the high-frequency coefficients of each layer are soft-thresholder, and the estimated coefficients are obtained by mapping the soft threshold function.

The low frequency coefficients and the processed high frequency coefficients are subjected to wavelet inverse transformation to realize reconstruction and denoising.

1.The reconstructed image is added to the edge image retained by ① to obtain a denoised image that preserves the details of the image.

$$\omega = \begin{cases} sgn\big(\omega \cdot (|\omega| - T)\big) & |\omega| \geq T \\ 0 & |\omega| \leq T \end{cases} \tag{4}$$

The denoising method is used in this paper, and compared with the denoising method of noise standard deviation estimation method proposed by Donoho and Johnstone. The simulation results are shown in Fig. 2

Figure 2. Comparison of simulation results

In addition, in order to further evaluate the effect of wavelet transform and noise standard deviation estimation based on Canny edge detection, this study uses two evaluation criteria to compare the denoising results.

The results were evaluated by minimally the mean squared error (MSE) and peak signal-to-noiseratio (PSNR). The calculated formulas were:

$$\mathrm{MSE} = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} \left(\hat{f}(i,j) - f(i,j) \right)^2 \tag{5}$$

$$\mathrm{PSNR} = 10\lg\left(\frac{255^2}{MSE}\right) \tag{6}$$

$\hat{f}(i,j)$ is the restored image, $f(i,j)$ is the original image, The results available.

Comparison of the results of the two denoising methods As shown in Table 1, it can be seen that the denoising method proposed in this paper is superior to the Donoho method. In addition, the edge detection effect also directly affects the quality of the final de-noising, the use of different edge detection algorithm (this chapter uses Canny operator), the edge of the image is not the same, Will get different denoising results.

Denoised image		Salt and pepper noise	Gaussian noise	Salt and pepper+Gaussian noise
MSE	method 1	0.6896	346.7823	416.8321
	method 2	0.6055	222.4803	289.7388
PSNR(dB)	method 1	49.74	22.73	21.93
	method 2	50.31	24.66	23.51

3.3. Edge detection

The performance of the traditional Canny operator is determined by three parameters: smoothing the parameters σ and the two thresholds required for the tracking process, the low threshold h1 and the high threshold h2. The traditional method is to rely on experience to manually set.

Because of the imaging conditions of aerial images, the interference of environmental factors can not be the same, so set a single threshold can not meet the needs of various situations, we must adopt an optimal threshold of the automatic selection algorithm. Otsu algorithm is an adaptive threshold determination method based on the maximum interclass variance. The experiment proves that the method is simple, stable and effective, and it is a widely used threshold method.

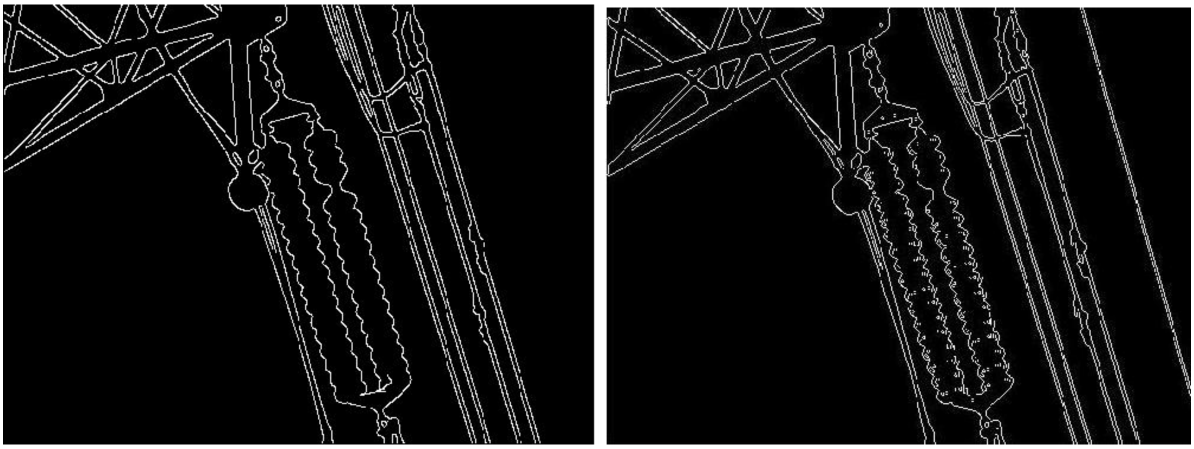
For an image with a pixel number of N and a gray scale range of [0, L- 1], it can be roughly divided into two parts of the target region A and the background region B, assuming that their segmentation thresholds are gray scale values T, their maximum classes The variance is:

$$\sigma^2(T) = \omega_A(\mu_A - \mu)^2 + \omega_B(\mu_B - \mu)^2 = \omega_A\omega_B(\mu_A - \mu_B)^2 \tag{7}$$

Where ω is the maximum variance between the two classes; ω_A is the pixel probability of region A, ω_B is the pixel probability of region B; $\mu_A$is the average gray level of class A, μ_B is the average gray level of class B, μ is the image average gray The The gray value T, which is the maximum value of $\sigma^2(T)$, is the optimal threshold obtained by Otsu algorithm.

Let $h_2 = T$, $h_1 = h_2/2$, then get the optimal double threshold of Canny operator.

Smoothing parameter σ selection, usually select σ = 2, since the image has been effectively filtered during the aerial image preprocessing stage, so σ can be selected as smaller, ie σ = 1. In order to analyze the effectiveness of the algorithm, the author carries on the experiment to the insulator image of a large number of transmission lines, and compares this method with the edge detection method based on Canny operator respectively. The edge detection results of the two algorithms are shown in Fig. 3



In addition, in order to further evaluate the effect of wavelet modulus maxima and Canny operator edge detection method, this paper uses two evaluation criteria to compare the edge detection results.

Edge continuity R:

$$R = \frac{CEN}{TEN} \tag{8}$$

In the formula: CEN - the total number of consecutive edge pixels, TEN - the total number of edge pixels.

Edge degree of order M_e:

M_e=(1-N) (1-F)

In the formula: N - false detection rate; F - false detection rate; Me the greater the edge of the edge of the image the better orderly.

The results of the two methods are shown in Table 2. It can be seen that the R and Me methods of this research method are higher, that is, the improved Canny algorithm has better edge continuity and order degree, and can get better edge detection effect.

Table 2. Comparison of edge detection between two operators

Detection method	Edge continuity	Edge degree of order
Canny operator	0.9387	0.8023
Improved Canny operator	0.9652	0.9548

4. THE IDENTIFICATION AND FAULT DIAGNOSIS OF INSULATOR

4.1. The principle of Hough transformation

Hough transform defines the mapping relation between image space and parameter space. Points in the image space can be mapped to a curve or surface of the parameter space through coordinate transform. The mechanism of voting is adopted to achieve the detection and identification of the target object. Firstly, the parameterized equation should be defined. Then the information in the image space can be transformed to the parameter space by utilizing this equation to realize the coordinate transformation. In the process of transformation, the data in the parameter space should be statistically accumulated. Thus, whether the original space has the detection target can be determined by searching the peak value of accumulator and setting the threshold value.

4.2. Elliptical recognition based on improved Hough transformation

In most transmission line images, the contour of the insulator is ellipse. Hough transformation can be used to detect the specific structure by setting the parameter equation. This study can realize the detection of insulators by improving Hough transformation. The ellipse contains five parameters: ellipse center (x_0,y_0), corner α, long axis 2a and minor axis 2b. Compared to the two-dimensional parameter space of the straight line, the parameters of the ellipse are five dimensions which the computation volume increases sharply. Only one-dimensional accumulator can accumulate the length of elliptical minor axis by reducing the five-dimensional parameter space to one dimension. It can reduce storage space and speed up operation. At the same time, the ellipse in the insulator edge image is not complete due to the shooting angle. Based on the mathematical properties of ellipse, the advantage of elliptic long axis can accelerate the detection speed of insulator and can realize the detection of incomplete ellipse.

According to the mathematical model of the ellipse, the two endpoints of the ellipse are supposed to be pixels (x1, y1) and (x2, y2). Therefore, the calculation formula of elliptic parameters can be derived to:

$$\mathrm{x}_0 = \frac{x_1 + x_2}{2} \tag{9}$$

$$\mathrm{y}_0 = \frac{y_1 + y_2}{2} \tag{10}$$

$$\mathrm{a} = \frac{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}{2} \tag{11}$$

$$\alpha = \arctan\frac{y_2 - y_1}{x_2 - x_1} \tag{12}$$

According to the derivation above, the five parameters of the ellipse can be obtained. Five-dimensional parameter space dimensionality reduction is realized in this study. Only one-dimensional accumulator is established to realize the statistics for the short axis half (b). The purpose of detecting ellipse can be achieved by detecting peak value, setting threshold value and utilizing voting principle.

The algorithm steps of Elliptical recognition based on improved Hough transformation are as follows:

(1) The one-dimensional array A is established to store all edge pixel points in the binary image, and the accumulator is established and reset.

(2) The edge pixels of the array are given to (x_1, y_1) in order. Repeat steps (3) ~ (8) to (x_1, y_1) of each point;

(3) Find (x_2, y_2) to make the distance between the points (x_1, y_1) and the point (x2, y2) greater than the threshold. Repeat (4) ~ (8).

(4) According to the pixel points (x_1, y_1) and (x_2, y_2), the four parameters of the ellipse can be calculated: the ellipse center (x_0, y_0), the angle α, and half of the long axis a;

(5) Find (x, y) to make the distance between the points (x, y) and the point (x_0, y_0) greater than the threshold, and less than the distance of (x_1, y_1), and (x_0,y_0). For all possible points (x, y), calculate the ellipse parameter b, increase the accumulator.

(6) Check the peak value of the accumulator. If it exceeds the threshold, it is a true ellipse. The ellipse parameter can be stored in array B.

(7) Remove all the pixels in the real ellipse which are detected from array A. Reset the accumulator.

(8) Mark the detected ellipse in the edge image.

(9) End.

This study used the algorithm above to deal with the edge image of insulator, which can realize the detection of incomplete ellipse and get elliptic parameters. There may have ellipse of non-insulators. The insulator string has certain similarity which can be further classified.

4.3. Fault Diagnosis of Insulators

In this study, identification Insulator is achieved by improved Hough transform. According to the insulator on the parameters of information, can be completed insulator out of fault diagnosis. The diagnostic algorithm is as follows: (1) Determine the insulator string. The ellipse angles on the same insulator string are the same, and the straight lines are detected using the rotation angle α and the ellipse center (x0, y0). Two straight lines are extracted and the elliptical centers on the straight lines are stored in two arrays. (2) the number of statistical insulators. Select the same voltage level of the same area of the insulator string for fault diagnosis, the number of insulator pieces must be. The number of individual insulator strings in the 220-kV transmission line image taken here is 17. Statistics (1) the length of the array, if the array length of 17, insulator string did not occur out of the chip, if the array length is less than 17, you need to further determine. (3) Calculate the spacing information of adjacent insulators. For each array, take any elliptical center (xi, yi), calculate all other elliptical centers and their distance d, as array D. Calculate the ratio e (rounded rounded) of the sub-small value d2 and the minimum value d1 in the array D and store it in the array E. Cycle until the corresponding e of each ellipse center (xi, yi) is calculated.

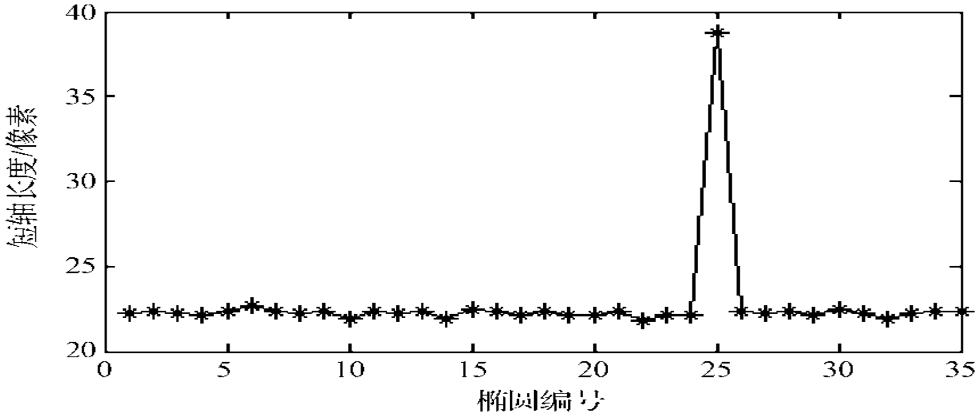
$$e = \left[\frac{d_2}{d_1} + 0.5\right] \tag{13}$$

(4) Insulator fault diagnosis. For the normal insulator string, both ends e = 2, the remaining insulator sub-e = 1, otherwise, there are pieces of failure. For array E, the number of statistics e = 2 m, if m = 2, and the remaining e are 1, then the insulator intact, otherwise the insulator has dropped.

In this study, by calculating the spacing information e of the adjacent insulator pair, if the failure occurs in the middle of the insulator string, fault diagnosis can be realized regardless of whether the insulator string is complete. If the chip occurs at both ends of the insulator string, a missed test occurs and is not suitable for the study of the algorithm.

5. RESULTS AND ANALYSIS

According to the algorithm proposed in this study, the author carries on the experiment to the aerial insulator image. Using the improved Hough transform to detect the insulator, will get all the elliptical mathematical information, that is, five parameters of the ellipse. I measured the parameters of all the ellipses detected information, and were compared classification, which short axis length statistics shown in Fig. 4



In this study, we can find the mutation point, that is, the ellipse with number 25, which can remove the interference information, remove the background ellipse from the image, mark only the real insulator, and realize the insulator to identify it accurately, as shown in Fig. 5

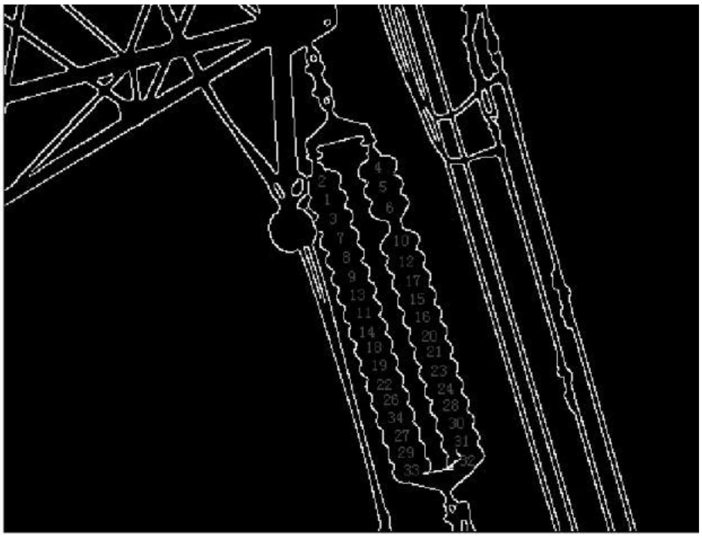


Fig. 5

According to the insulator fault diagnosis algorithm, the number of insulators is counted, and the number of slices is not 17, and the spacing information of adjacent insulators is calculated. The number of e = 2 is 4, and the condition is not satisfied. In order to verify the accuracy of the method of the study, another 100 insulator images were experimented. Among them, the normal insulator image 80, out of film image 20. The author uses the algorithm proposed in this study to deal with the transmission line insulator image, successfully detect the insulator profile 100, can find 19 fault images, a leak detection, the reason for the failure occurred in the top of the insulator string. The failure rate of the insulator is 95%.

6. CONCLUDING REMARKS

In this paper, a fault diagnosis method based on improved Hough transform is proposed, which is divided into four steps: (1) preprocessing the image using optical correction, based on Canny edge detection wavelet transform denoising, reduce the image detail and calculation, the target and background distinction is better; (2) Using the improved Canny operator to detect the edge of the image, we obtain the edge image with high continuity and continuity. (3) Using the improved Hough transform to detect the ellipse, speed up the detection speed, and can detect the ellipse with incomplete edge, improve the detection effect, design the classification condition to remove the background; (4) Based on the insulator parameter location information, the algorithm is designed to realize the insulator fault diagnosis. The stability of the method was verified by experimenting with 100 insulator images. The experimental results show that the algorithm can accurately detect the insulator contours in the inspection image of the grid and judge the failure of the insulator, which has high versatility and engineering application value. The method is simple and effective, which provides a new concept and technical means for the insulator inspection in China's smart grid.

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