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A Vision-based method for the Broken Spacer Detection

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***Abstract*—Power line inspection is essential to the smooth running of the power grid. In the past, the power line inspection was mainly carried out manually, which means the liners had to inspect the power line in the field or watch the inspection video taken by UAVs or inspection robots. The manual inspection method is with disadvantages such as long time consumption and high manual labor cost. With the rapid growing of power grid, the demand for the power inspection has been continuously increased, but the manual inspection method can hardly meet the requirements for the power inspection due to its disadvantages. This paper presents a computer vision-based method for the broken spacer detection. The method is mainly implemented in three steps. First of all, the spacer is recognized in the region of interest. Secondly, the image morphology is used to extract the image feature. At last, we determine the broken spacer fault by the analysis of the connected domain in the image. Experimental results have successfully demonstrated the effectiveness of the proposed method.**

I. Introduction

The power line inspection is carried out to find the power line fault and damage, which is essential to the smooth running of the power grid. In the past, power line inspection was mainly carried out manually. The liners had to finish the inspection in the field or watch the inspection video taken by UAVs or inspection robots. The manual inspection is with disadvantages such as long time consumption and high manual labor cost. The intelligent detection of power line fault and damage is thus practically required for the normal running of power grid systems.

So far, there have been researches on the intelligent detection for power line fault and damage. According to the sensory techniques, the detection methods can be categorized into the vision based method and the novision based method.

For the vision based method, [1] introduced a vision-based method of the broken strand detection. In the method, the image feature of histogram of gradients was extracted in the region of interest (ROI), and the broken strand fault can be detected by the classification of the histogram of gradients. In [2], a robot system was set up to detect a spacer in quad-bundled conductors. The detailed process could be described in the following steps: digital image acquisition, conductor localization, and spacer detection. One or more disruptions of conductors were sufficient proof that a spacer was present. In [3], the repetitiveness feature which described the relationship between each structural element of insulator was employed for the insulator faulty diagnosis. [4] purposed a method for the detection of the porcelain insulator fault. The insulator was first recognized and located based on its local feature via a 3-layer BP neural network, and then the status of the insulator was determined by analyzing the mode of vertical section line.

For the nonvision based method, a high-temperature superconductor superconducting quantum interference device was used to detect single-wire breakage in aluminum transmission lines [5]. A periodic pattern was detected with wire breakage, while this pattern was not observed in the normal wire. Using electromagnetic-acoustic transducers, [6] presented a nondestructive inspection system to diagnose the mechanical integrity of conductors.

Each of the nonvision-based and vision-based methods has its advantages in power line detection. The advantages of the vision-based method include the easy collection of the vision sensory data, similarity to the traditional manual inspection and the strong versatility to power line faults.

In this paper, we proposed a computer vision-based method to detect the broken spacer fault, which can result in the severe accident in the running of power grid. The method is mainly implemented in three steps. First of all, the spacer is recognized in the image as the region of interest(ROI). Secondly, the image morphology is used to extract the image feature. At last, we determine the broken spacer fault by the analysis of the connected domain in the image. Experimental results have successfully demonstrated the effectiveness of the proposed method.

The remaining paper is organized as following: Section II introduces the background of the broken spacer fault. Section III gives the detail of the detection method, including the ROI selection, image feature extraction and the fault determination by the analysis of image features. In Section IV, we show the experimental results. Finally, the conclusion and future work are given in Section V.

II. Background of Broken Spacer Detection

Extra-high voltage transmission lines mainly consist of overhead ground wires (OGW), towers, conductors and some devices with special functions, as shown in Fig.1.

Bundle conductors are widely used for the delivery of high amounts of current. Compared with a conductor, bundle conductors own better performance on delivery capability, cost and weight [7].

Fig. 1. 500kV Power transmission lines

Bundle conductors consist of several parallel cables connected at intervals by spacers, which keeps the sub-conductors (cables) of a bundle in a given geometrical configuration. The broken spacer cannot keep the given configuration for the conductors so that the conductors' performance on the power delivery is greatly decreased and the different bundles conductors will attract each other to lead to a collision. For these reasons, the spacer detection is an important part of power line detections, which are essential for the smooth running of the power grid.

III. Broken Spacer Detection Method

A. Overview of the Detection Method

In the power grid, there have been plenty of intelligent power line monitoring systems(e.g. power line inspection robots and visual monitoring systems), which can provide the inspection images of spacers for the proposed broken spacer detection.

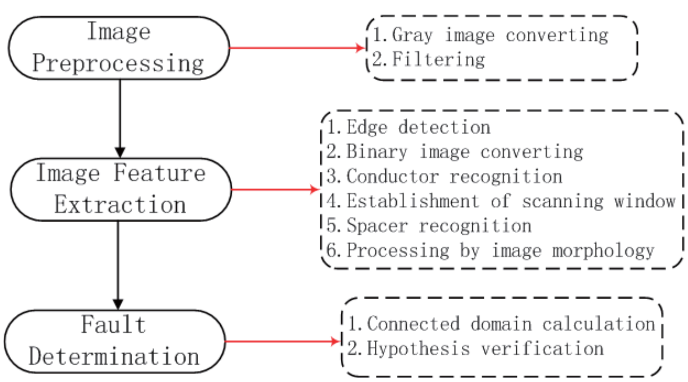

Fig. 2. Framework of the detection method

Fig. 2 gives the framework of broken spacer detection. At first, the image preprocessing is carried out for the conversion of color image into gray image and the noise reduction. After the conversion to binary image and edge image, the conductors are recognized and located through the Hough transform and the width of conductors is calculated as the reference value of the scanning window's length. The scanning window moves in the direction of the conductor in the binary image to recognize the spacer by finding the minimum value of the sum of elements of the binary image matrix. The window containing the spacer is selected as ROI. In ROI, the morphological closing and opening are respectively implemented for the image reconstruction. At last, the number of connected components is counted to determine whether the spacer is broken.

B. Image Preprocessing

Before the detection method can be applied to image data in order to extract some specific piece of information, it is usually necessary to process the data in order to assure that it satisfies certain assumptions implied by the method. Here, the color images is firstly converted into gray image so that the hue information of the images can be deleted. After that, the noise in the image is reduced through the median filtering in order to assure that sensor noise does not introduce false information.

C. Image Feature Extraction

At first, the binary image and edge image are respectively converted for the conductor recognition and the spacer recognition. We use Otsu's method to get the binary image[8]. The Otsu's method assumes that the image contains foreground pixels and background pixels, it then calculates the optimum threshold which separates the two classes so that their combined spread is minimal. The Canny edge detector[9] is then used to get the edge image due to its robustness to various environments.

We can use Hough transform to extract the edges of the conductors, because the edges of conductors are all straight lines in the edge image. For the quad-bundled conductors, there are eight lines with strongest intensity in Hough space, which are picked as the conductor edges. The mathematical formulation of the conductor edges can be given as:

$$u\cos\beta_i + v\sin\beta_i = \rho_i (i = 1, 2 \cdot\cdot, 8)$$

and each conductor can be recognized with a minimum distances between two edges. We can also calculate the average conductor width by measuring the distances between the conductor edges:

$$w_d = \begin{bmatrix} \sin\beta & \cos\beta \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta v \end{bmatrix}$$

After the recognition of the conductors, a scanning window should be established for the recognition of the spacer. The length and width of the scanning window are set as $K_l w_d$ and $K_w w_d$, where w_d is the conductor width and K_l, K_w are the proportionality coefficients relating the real geometric dimension of the spacer to the conductor. The binary image is used for the scanning process. The right nether corner point of the scanning window is set in a recognized conductor and the scanning direction is along the direction of the conductor.

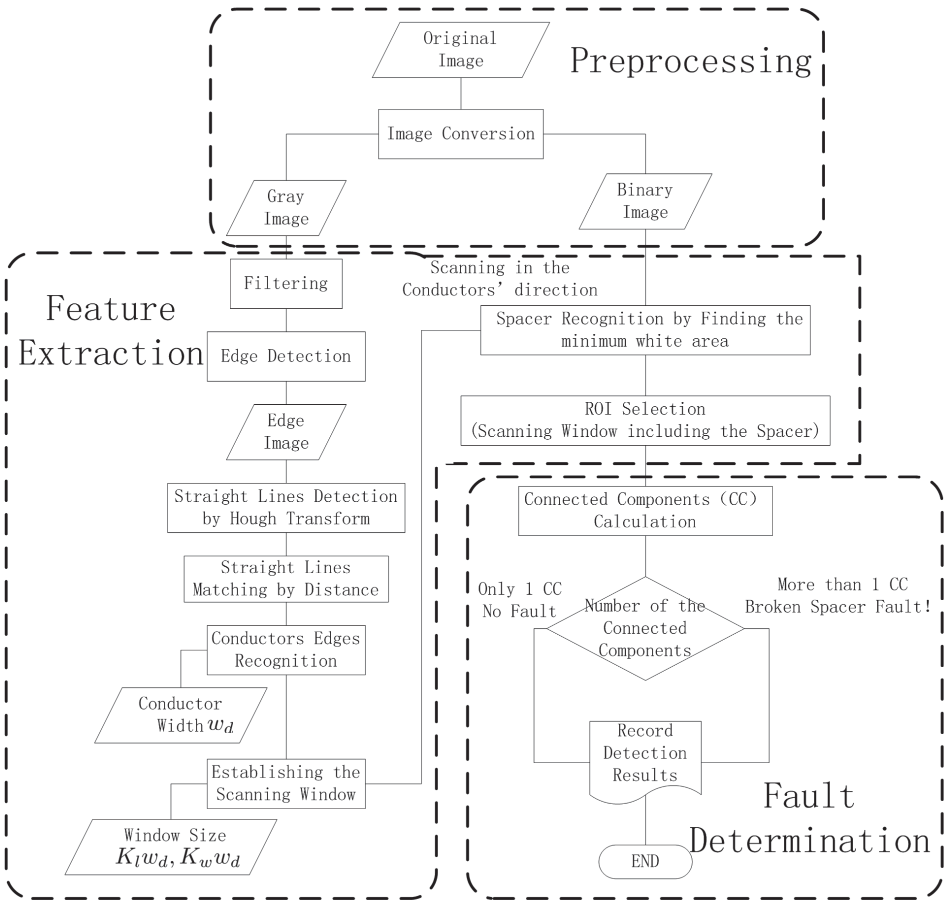

Fig. 3. Detection process

The binary image is a logical array of 0s and 1s. Here, the background is white (1 value) while the objects of the spacer and conductors are black (0 value). A function is established to sum all the elements of the array in the scanning window and thus we can figure out the portion of spacer and conductors in the scanning window. We can locate the spacer by finding the minimum value of the function. The scanning window with the corresponding function being minimum value is then selected as the ROI.

In the ROI, the binary image is first inverse and a combination of morphological operations, which consisting a closing and an opening, are carried out to improve the binary image:

$$Closing : A \cdot B = (A \oplus B) \ominus B$$

$$Opening : A \circ B = (A \ominus B) \oplus B$$

where A is the inverse binary image, and B is a square with the side length equal to the conductor width.

The morphological closing joins the narrow breaks and small holes inside the spacer, while the morphological opening breaks the thin connection between the spacer arms.

D. Fault Determination

After the morphological operations, the broken spacer fault can be determined by the counting the number of connected components. If none of spacer arms is broken, all of the conductors and the spacer are connected, i.e. there is only 1 connected component. Otherwise, there are serval connected components due to the broken arms of the spacer.

IV. Experimental Results

A. Image Preprocessing

The images taken by the intelligent power line monitoring systems are used for the method verification, as shown in Fig. 4. The camera parameters has been set beforehand for the intelligent power line monitoring systems to get the objects of the conductors and spacers.

Fig. 5 shows the gray image which is converted from the original image, and the gray image through the median filtering for the noise reduction.

B. Image Feature Extraction

The upper figure and the nether figure of Fig. 6 respectively show the edge image and the binary image. The edge image

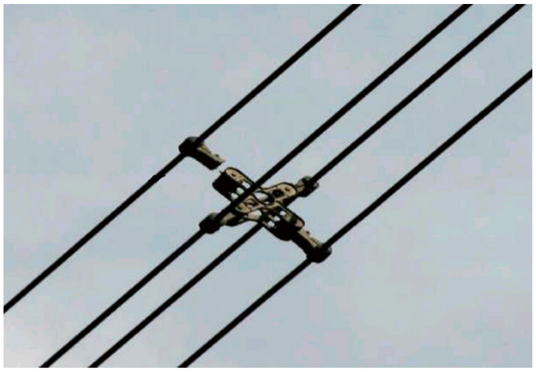

Fig. 4. Original image

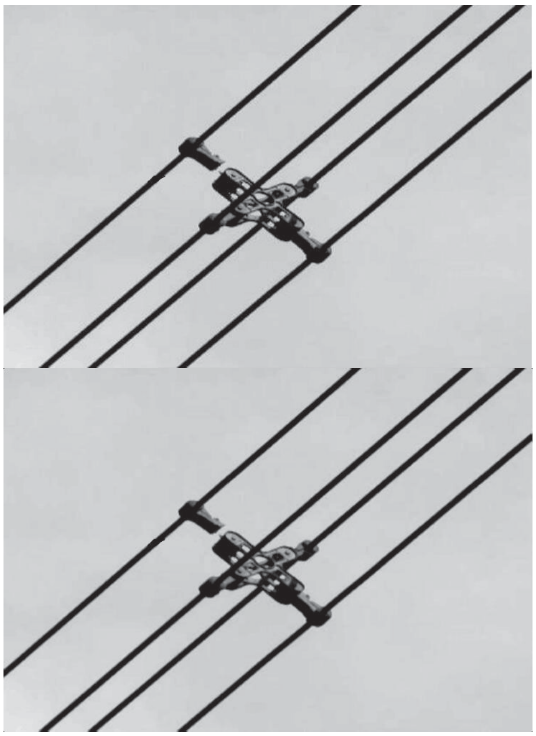

Fig. 5. Gray image before and after median filtering

is used for the conductor recognition, While the binary image is used for the spacer location.

Through the Hough Transform, eight straight lines, whose intensity is strongest in the Hough space, are extracted as conductor edges, as shown in Fig. 7. And then we calculate the distances between each straight line to the other seven straight lines. The two straight lines, between which the minimum distance is, are matched as the edges of one conductor. By this way, there are totally four conductors recognized in Fig. 7. The conductor' average width is calculated as the reference value of the parameters of the scanning window.

The scanning window used for the conductor recognition is a moving rectangle region in the binary image. The length and width of the scanning window is set as $K_l w_d$ and $K_w w_d$, where w_d is the conductor width and K_l, K_w are proportionality coefficients relating the real geometric dimension of the spacer to the conductor. Fig. 8 shows the scanning process: the right

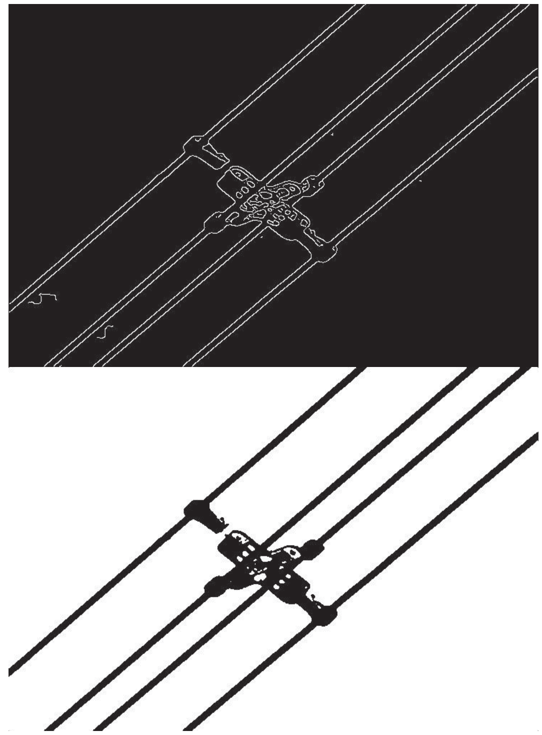

Fig. 6. Upper:Edge image; Nether: Binary image

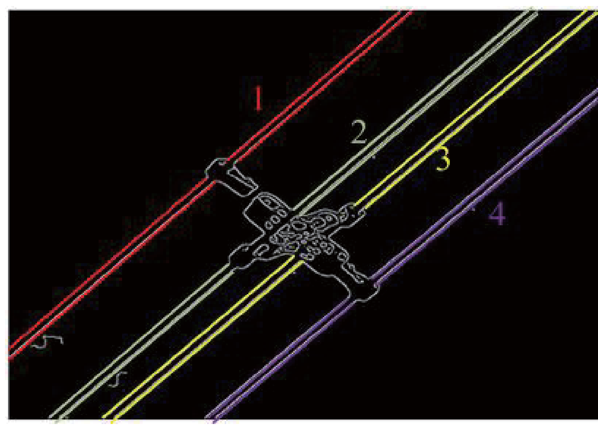

Fig. 7. Conduction recognition

nether corner point of the scanning window is set in the conductor 2 in Fig. 7, and the window moves one step for each scanning along the direction of the conductor 2.

A function is established to sum all the elements of the array in the scanning window, the spacer can be located in the scanning window with the the minimum function value, as shown in Fig. 9. Thus, the region in the scanning window with the the minimum value of the function is selected as ROI. The image in ROI is then turned to be inverse for the further processing.

In the inverse image, a combination of morphological operations,which consisting a closing and an opening, are implemented. The closing is firstly used to join the narrow breaks and small holes inside the spacer, and then the morphological opening breaks the thin connection between the spacer arms.

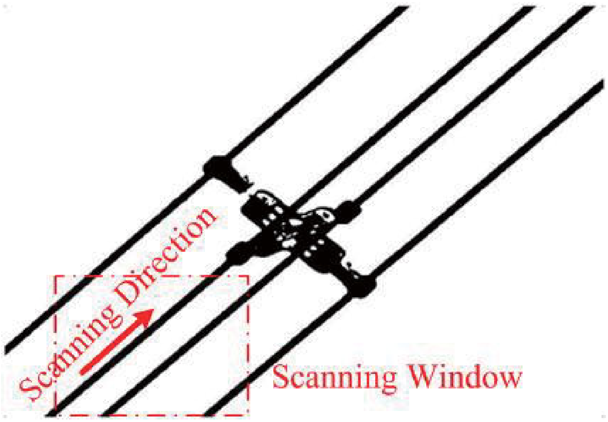

Fig. 8. Scanning to search the spacer

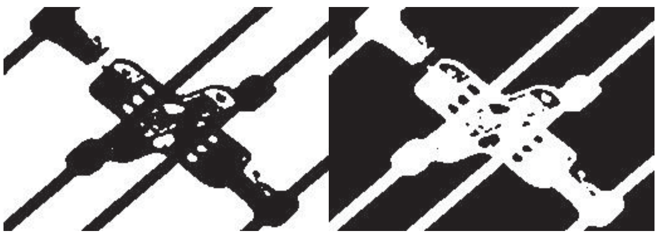

Fig. 9. Left:Region of interest(ROI);Right: Inverse ROI

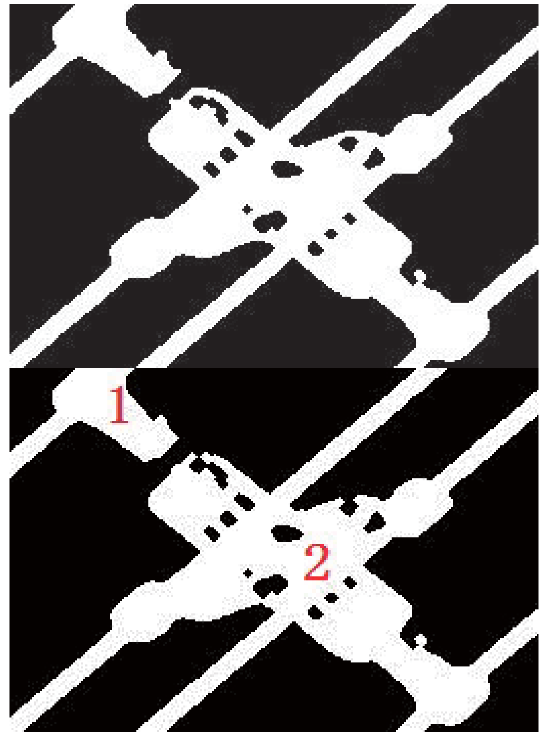

Fig. 10. Morphological operations: Upper: Closing; Nether: Opening

The morphological operations are helpful to break the thin connection between the spacer arms and fill the small holes inside the spacer.

C. Fault Determination

The normal spacer can connect all four conductors as a connected component, whereas the broken spacer disjoints the conductors into serval connected components. We can determine whether the spacer is broken by counting the number of connected components. The nether figure of Fig. 10 shows two connected components, which means the spacer is broken in this situation.

V. Conclusion

This paper presents a vision-based method for detecting the broken spacer. The method is mainly implemented in three steps. First of all, the spacer is recognized in the image as the region of interest. Secondly, the morphological operations are used to extract the image feature. At last, we determine the broken spacer fault by the analysis of the connected domain in the image. The effectiveness of the proposed vision-based broken spacer detection method is demonstrated by the experiment studies.

In our future work, our research will be oriented towards the improvement of the detection method by considering the complex image background and environment illumination condition. Furthermore, for the practical application requirement, the method needs to be verified by many more samples.

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