Investigating the Detection of Overhead Ground Wire Broken Strand though Power Line Robots

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Abstract—Power line inspection and maintenance robots have been developed for more than two decades as a substitute for linemen to work under the dangerous working condition. The fault and obstacle detection through the information collected by robot sensors is an important research filed. Currently, visual information remains the most common, practical and easily collected data for robots amongst all kinds of sensing data. This paper presents a visual detection method for the broken strand fault. The broken strand fault can be detected by judging the intensity distribution of histogram of edge gradient (HOEG) in the following steps: at first, the region of interest (ROI) of captured images is selected; then, the HOEG descriptor is extracted in ROI as image feature; at last, the intensity distribution of HOEG descriptor can differentiate the broken strand fault from the normal wire. In addition, the location of detected broken strand fault is given for the practical repair. Both laboratory and field experiments results have demonstrated the effectiveness of the proposed method.

I. INTRODUCTION

Power line inspection and maintenance is indispensable to the normal running of power grid system. To detect the power line faults, specialized workers have to carry out the inspection and maintenance tasks under the high voltage live line condition, which can cause great risks and high working intensity. The utilization of the power line inspection and maintenance robot is thus practically demanded for power grid systems.

To satisfy the practical requirements of power line inspection and maintenance, the robotic technology has been applied to implementing the inspection and maintenance tasks [1-12]. [1-6] introduces the robots, which are designed to carry out the conductor and the overhead ground wire (OGW) inspection task. In [7], a robot is developed for the de-icing maintenance task. [8,9] introduces a robot, which can install the warning ball in the OGW instead of workers. [10-12] introduces a robot named LineScout, which can not only implement the inspection task, but also be equipped with a variety of special tools for the maintenance tasks, such as tightening the screws and repairing the broken strand.

The detection of power line faults is an important field of research for power line robots. We mainly categorize the detection methods by the used sensory techniques: non-vision based method [13-15] and vision based method [16-21].

For the non-vision based method, [13] introduced the inspection robot, which depended on map navigation and feedback information from ultrasonic and contact sensors to detect working environment. In [14-15], several sets of electromagnetic sensor arrays were installed on the robot to locate obstacles and detect the posture of the robot.

For the vision based method, [16-18] proposed an algorithm based on straight line extraction for the obstacle detection, such as insulators and counterweights. In [19], by finding the correspondence points in two images, a three-dimensional modeling was constructed for obstacle detection. In [20,21], a geometric model, which included the position relationship between the camera and the location center of obstacles, was built through using Hough transform for obstacle detection.

The broken strand is a kind of serious fault, which can result in the flashover, even the crash of power grid system. However, the broken strand has seldom been studied in the existing literatures due to the following reasons: there is not salient feature between broken strand fault and normal wire, which increases the difficulty of detection. The non-vision based method can hardly be applied, because the diameter of most strand is too small (less than 3 mm) and the broken strand pattern is of variety. The vision based detection method aforementioned mainly depends on the extraction of obvious geometric feature in obstacle image, but the extraction of such geometric feature in the broken strand image is quite difficult.

In this paper, we proposed a vision based method to detect the broken strand, which consists of three steps: at first, in the images captured by the power line robots, the region of interest (ROI) is selected; then, the histogram of edge gradient (HOEG) descriptor is extracted in ROI as image feature; at last, the captured images can be classified into normal wire class and broken strand faults class by judging the intensity distribution of HOEG descriptor. The proposed detection method is of high accuracy and low computational complexity. The effectiveness of the proposed method has been demonstrated through both laboratory and field experiments.
The remaining paper is organized as following: Section II introduces the background of broken strand fault. Section III gives the detail of the detection method, including the ROI selection, broken strand detection and the broken strand location calculation. In Section IV, we show the experiment results and comparative studies. Finally, the conclusion and future work are given in Section V.

II. THE BACKGROUND OF BROKEN STRAND DETECTION

Power transmission lines consist of OGW, conductors, and several kinds of fittings. The OGW is installed above the conductors for the lightning protection of the power grid system and the safety for running condition. However, the huge current transferred to the ground by OGW during the lightning may result in a local overheating and make the strand melting to be a broken strand. In addition, the line vibration is another factor which may cause broken strand. As the broken strand could reduce the distance from OGW to conductors, the huge potential difference between them can easily form a voltage breakdown and flashover, which results in a severe damage in power grid and enormous economic losses. Another harm of broken strand is the reduction of OGW strength, and the line tension may result in the multiple broken strand, even the fracturing of whole OGW. Fig. 1 shows the typical broken strand fault in power grid.

Fig. 1. The broken strand in extra-high voltage power transmission line. (a) Extra-high voltage power transmission line. (b,c) Broken strand in OGW.

Because the broken strand does great harm to the power grid, the broken strand fault needs to be detected and repaired in time. In the traditional manual way, workers have to carry out the inspection or maintenance task in the forest, grass, mountain and other complex geographical environments. Sometimes, workers have to climb the towers and ride in a gondola suspended on the OGW during the maintenance task. The poor working environment makes the maintenance work difficult to implement.

For these reasons, the power line robot is proposed to inspect and repair the broken strand fault instead of workers, as shown in Fig. 2. The broken strand detection, which can identify the fault from normal wires and confirm its location, is essential for the robot system.

III. BROKEN STRAND DETECTION METHOD

The framework of broken strand detection procedure is as shown in Fig. 3. The process can be described as following:

A. ROI Selection

To remove the unnecessary part of the image and reduce the amount of computation, ROI should be first selected from the original image for the further processing.

The original image captured by the camera is shown in Fig. 4-a. In order to get a clear contour of the strands for the broken strand detection, ROI is obtained from the upper part of the image, which is close to the camera and exhibits high resolution. A narrow strip part of image in the upper image is first obtained and turned into gray image as the initial ROI, as shown in Fig. 4-b. Because the initial ROI is usually with backgrounds that owns similar gray values with the strands, the histogram equalization needs to be implemented to regulate the gray intensity distribution. By effectively spreading the most frequent intensity values out, the initial ROI with a stronger global contrast is shown in Fig. 4-c. After that, the image edge is detected with Canny edge operator as shown in Fig. 4-d.

Because the initial ROI is usually with backgrounds that owns similar gray values with the strands, the histogram equalization needs to be implemented to regulate the gray intensity distribution. By effectively spreading the most frequent intensity values out, the initial ROI with a stronger global contrast is shown in Fig. 4-c. After that, the image edge is detected with Canny edge operator as shown in Fig. 4-d.

After the initial ROI selection, the OGW edge needs to be extracted for the further removal of unnecessary part. Because the OGW edge is in the vertical direction, the Hough transform is used to extract all of the vertical straight lines, which are marked as green lines in Fig. 4-e. Among all the straight lines
which are extracted from the edge image, two edges of OGW should satisfy two conditions: 1. the distance between two OGW edges is the width of the wire; 2. the centerline of two OGW edges should in the center of the image due to the installation relationship between the robot and OGW, which can be formulated as:

\[
|\bar{x}_1 - \bar{x}_2| < \delta \\
|\bar{x}_1 + \bar{x}_2 - d_i| < \gamma
\]

where \(\bar{x}_1\) and \(\bar{x}_2\) stand for the \(x\) coordinate mean value of all points on the left and right edge of OGW respectively. \(d_i\) is the width of image. \(\delta\) and \(\gamma\) are pre-defined thresholds.

Through the method mentioned above, the edges of OGW can be extracted. The final ROI can be selected by retention of the region between the left and right edge of OGW, as shown in Fig. 4-f. After ROI selection, the unnecessary parts of image have been removed and OGW visual features are well reserved for the further processing.

B. Broken Strand Detection

After ROI is selected, we extract HOEG descriptor as the image feature for the broken strand detection.

The broken strand processes many similar features with the normal wire, e.g. gray intensity distribution and image edge. As shown in Fig. 5. However, the broken strand affects the strand configuration of OGW. For the normal wire, all strands winds the OGW axis as helix. In this case, the edges extracted from ROI could mainly distribute in two principal directions, the OGW edge in vertical direction and the strands in spiral-lead angle direction, as shown in Fig. 5-a. On the other hand, the broken strand affects the strand configuration, and it leads to the increase of edges in other directions, as shown in Fig. 5-b. The pixels of image edges for broken strand fault are mainly in the vertical direction and spiral-lead angle direction, but the pixels of image edges of the broken strand fault comprise a lower percentage amongst all edge pixels than that of the normal wire due to the different configuration of the broken strand.

Based on the above analysis, the HOEG in ROI is chosen as the image features to determine whether the wire is with the broken strand fault. The concrete steps of the HOEG descriptor calculation is as following.

First, the Gaussian filter is used in ROI for the image filtering. And then gradient value is calculated in both of the horizontal and vertical directions. After that, the direction and magnitude of the gradient could then be calculated by (3) and (4), and the image edges should be extracted with Canny edge operator. For the pixels on the image edges, their gradient information have been calculated in the last step. We can set a histogram with the number of bins being 72, i.e. each \(5^\circ\) is the range of a bin. The number of pixels is accumulated for each bin. The bins in the vertical and spiral-lead angle direction are much higher than the bins in other directions because of the configuration of normal strands.

\[
\nabla f = \frac{\partial f}{\partial x} \hat{x} + \frac{\partial f}{\partial y} \hat{y}
\]

\[
\theta = \arctan\left(\frac{\partial f}{\partial y}, \frac{\partial f}{\partial x}\right)
\]

where \(\frac{\partial f}{\partial x}\) and \(\frac{\partial f}{\partial y}\) stand for the horizontal and vertical gradient magnitude.

The HOEG descriptor is a normalized array whose elements are corresponding bins of the aforementioned histogram. The number of pixels in the the vertical and spiral-lead angle direction can be represented by the corresponding local HOEG descriptor intensity, i.e. the sum of elements in certain positions. The broken strand fault can be detected by comparing the HOEG descriptor intensity in the the vertical direction \(I_{\text{EdgeWire}}\) and spiral-lead angle direction \(I_{\text{EdgeStrand}}\) and two thresholds set beforehand, \(TH1\) and \(TH2\):

\[
I_{\text{EdgeWire}}I_{\text{EdgeStrand}} \geq TH1 \Rightarrow \text{Normalwire} \\
TH2 \leq I_{\text{EdgeWire}}I_{\text{EdgeStrand}} \leq TH1 \Rightarrow \text{Brokenstrand}
\]

C. Location of Broken Strand Fault

For the practical repair requirement, the broken strand fault detection should include the fault location calculation. Fig. 6 is a schematic view of an inspection and maintenance robot that works in a inclined OGW and detects the broken strand between point \(A\) and \(B\).

In Fig. 6, \(l\) is the length of electrical box; \(l_1\) and \(l_2\) are the length of upper and nether parts of robot arm; \(c\) is the distance between the front arm and the camera mounting point; \(\beta\) is the view angle of the camera; \(\alpha\) is the coangle of the camera tilt angle.
Climbing the inclined line could result different pressure forces on front and rear driving wheels. As the resetting springs are installed at the joint of robot upper and nether arm, the joint deformation, which are caused by the different pressure forces, is marked as $\rho_1$ and $\rho_2$. Particularly, $\rho_1$ and $\rho_2$ are not the same while the robot is in the inclined line. Therefore it could cause a small angle $\varepsilon$ between the OGW and robot electrical box, which is formulated as:

$$
\varepsilon = \arctan\left(\frac{l_1(\cos\rho_1 - \cos\rho_2)}{L - l_1(\sin\rho_1 + \sin\rho_2)}\right)
$$

The OGW inclined angle can be calculated by adding $\varepsilon$ and the robot inclined angle, which is measured by another potentiometer. And $t$, the distance from the camera mounting point to the OGW is given as (7).

$$
t = c \tan \varepsilon + l_2 + l_1 \cos \rho_1
$$

In Fig. 6, $A, B, C$ are three points which are corresponding to the top, center and bottom pixel in the image and $O$ is the point by mapping the camera mounting point normally to OGW. According to the geometric relationships in Fig. 6, $OB$ can be formulated as (8).

$$
OB = \frac{t \sin \alpha}{\cos (\alpha - \varepsilon)}
$$

Similarly, $OA$ and $OC$ can be calculated in the same way.

$$
OA = \frac{t \sin (\alpha - \frac{\beta}{2})}{\cos (\alpha - \frac{\beta}{2} - \varepsilon)}
$$

$$
OC = \frac{t \sin (\alpha + \frac{\beta}{2})}{\cos (\alpha + \frac{\beta}{2} - \varepsilon)}
$$

Through (8)-(10), the position of three points $A, B$ and $C$, which are corresponding to top, center and bottom pixel $A', B'$ and $C'$ in the image as shown in Fig. 7, can be calculated. Because of the installation position of the camera, the OGW is always in the center of the image. Therefore, the corresponding position of other pixels can also be calculated with the camera image principle. As shown in Fig. 7, the point $D'$ in the image, which is at the bottom of ROI, is corresponding with the point $D$ in OGW, and its position is given as:

$$
OD = t \tan (\alpha - \arctan (\frac{B'D'}{A'B'} \tan \frac{\beta}{2}))
$$

As the position of $A'$ and $D'$ have been calculated, the location of broken strand between these points is given.

### IV. EXPERIMENT

#### A. The Laboratory Experiment

During the experiment, the images of OGW are captured first, and the horizontal and vertical gradient magnitudes are calculated in ROI. The HOEG descriptor is later calculated by accumulation of the number of image edge pixels according to their gradient direction.

![Fig. 8. HOEG descriptor in the laboratory experiment](image)

Fig. 8 shows HOEG descriptors of images captured in the laboratory experiment. The horizontal axis shows the gradient direction and the vertical axis shows normalized HOEG intensity. The HOEG descriptor of normal wire is mainly distributed in two directions, the vertical direction (around 290°) and the strands spiral-liter angle direction (around 120°). In Fig.8-a, the red arrows point at the aforementioned directions and the blue arrows point at two peaks of HOEG intensity in those directions. Compared with the normal wire, the broken strand...
affected the distribution of of HOEG intensity, as shown in red region of Fig. 8-b,c,d. The HOEG intensity of broken strand image is much lower than the normal wire around the two main direction aforementioned, which can be proved by the lower peaks pointed at by the green arrows in Fig. 8-b,c,d. The detection accuracy rate is related with the thresholds \( TH1 \) and \( TH2 \). In the trial of 100 normal wire and broken strand images detection, the detection accuracy rate can reach 92% while \( TH1 \) and \( TH2 \) are set 0.0493 and 0.0315 respectively.

\[ B. \ The \ Field \ Experiment \]

Fig. 9. OGW images captured in the field experiment

The proposed method has also been verified by field experiments. Fig. 9 shows the images captured in the field experiment. Similarly, Fig. 10 shows HOEG descriptors of images captured in the field experiment. The gradients of normal wire are mainly distributed in the vertical direction (around 210°) and the strands spiral-liter angle direction (around 60°) in Fig. 10-a,b. However, the HOEG intensity of broken strand image is much lower than the normal wire around the two main directions aforementioned, as shown in Fig. 10-c,d.

Fig. 10. HOEG descriptor in the field experiment

\[ V. \ CONCLUSIONS \]

This paper presents a vision-based method for detecting the OGW broken strand, which facilitates the practical application of power line maintenance robots. The vision-based detection method is mainly implemented in three steps, namely, the selection of the region of interest by the extraction of the OGW edge, the calculation of the histogram of edge gradient, and the detection of the broken strand fault by judging the HOEG intensity in vertical and spiral-liter angle direction. The location of the broken strand is calculated through the geometric relationship between robots and OGW. The effectiveness of the proposed vision-based broken strand detection method is verified and demonstrated by numerous experiment studies.

In our future work, we will focus on the improvement of the detection method by considering the environment illumination condition and the OGW vibration disturbance, and giving the estimation method for judging thresholds in different detection conditions.

\[ REFERENCES \]


