X-ray Image Processing Method for Buffer Layer Defect in High Voltage Cable

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Abstract: The original X-ray image of the high voltage XLPE insulated cable has low contrast due to its complexity and the limited imaging conditions. Therefore, an X-ray image processing method is proposed to address the high voltage cable’s buffer layer defect detection. One hundred seventy-seven high-resolution images from a cable tunnel are collected. The results indicated that our method could efficiently detect buffer layer defects.

1. Introduction
High voltage XLPE cable has become one of the core power equipment for large-capacity power transmission in cities due to its advantages such as excellent electrical performance, large transmission capacity, simple manufacturing process, easy installation and maintenance. The rapid growth of high voltage XLPE cable has posed more challenges to cable lines' operation and maintenance. In China, body failure caused by cable buffer layer ablation frequently is occurring in recent years [1-2].

Previous studies have shown that common detection techniques for existing power equipment, such as partial discharge detection, cannot effectively detect buffer layer defects [3-5]. The X-ray digital imaging technology [6] can effectively and intuitively carry out defect inspection on buffer Layer. However, the original X-ray image is not clear enough to detect the detects by naked eyes, which need image processing.

In this paper, on-site X-ray image data set collected from a cable tunnel is established. Then, the buffer layer defects are identified using the image processing method, thus providing an effective way for defect detection.

2. The image processing method flow chart
The flowchart of our image processing method is shown in Figure 1 and demonstrated as follows:

Step 1. Image noise reduction. After obtaining the X-ray digital gray image using a CCD or flat detector, noise reduction processing is carried out in the image, and noise reduction is carried out by optimizing the multi-graph average method.

Assuming that the noise is additive noise, which is specifically expressed as follows:

\[ g(x, y) = f(x, y) + \delta(x, y) \] (1)

where \( g(x, y) \) is the acquisition image, \( f(x, y) \) is the image without noise, \( \delta(x, y) \) denotes the noise.

For multiple images taken in the same scene, it can be considered that \( f_i(x, y) \) is the same, while \( \delta_i(x, y) \) is random and independent. The mean value of \( m \) images can be expressed as follows:

\[ g'(x, y) = \frac{1}{m} \sum_{i=1}^{m} [f_i(x, y) + \delta_i(x, y)] = f(x, y) + \frac{1}{m} \sum_{i=1}^{m} \delta_i(x, y) \] (2)

Because the noise is random and uncorrelated, the average image expectation can be obtained:
The variance of the average image:

\[ \sigma^2_{g'(x, y)} = \frac{1}{m} \sigma^2_{g(x, y)} \]  

From Equation (3), it can be seen that the expectation of the mean value of multiple images is a noiseless image. From Equation (4), it can be seen that by increasing the number of average images, the variance, namely image noise, can be reduced.

Step 2. Adjust the window width and window level. Since different areas in the image have different pixel values, the window width and window level suitable for observing the structure of the buffer layer should be selected when displaying the cable buffer layer to obtain the best display effect.

Step 3. Overall contrast enhancement. Enhance the overall grayscale image brightness and edge contrast to create a clearer, grayscale image and its boundary visually. In this study, we use the Gamma transformation, which can be expressed as follows [7]:

\[ V_{out} = V_{in}^\gamma \]  

where \( V_{in} \) is the output image gray value, \( V_{out} \) is the input image gray value, \( \gamma \) denotes the gamma value.

Step 4. Local contrast enhancement. The local grayscale image brightness and edge contrast are enhanced to make the visual defects and boundaries of the buffer layer image clearer. In this study, we use the adaptive contrast enhancement algorithm [8].

Assuming that a point in the image is represented as \( x(i, j) \), then take \( x(i, j) \) as the center, the window size is \((2n+1)\times(2n+1)\), and the local mean \( m_x(i, j) \) and local variance \( \sigma^2_x(i, j) \) can be expressed as follows:

\[ m_x(i, j) = \frac{1}{(2n+1)^2} \sum_{k=-n}^{l+n} \sum_{l=-n}^{l+n} x(k, l) \]  

\[ \sigma^2_x(i, j) = \frac{1}{(2n+1)^2} \sum_{k=-n}^{l+n} \sum_{l=-n}^{l+n} [x(k, l) - m_x(i, j)]^2 \]  

Define \( f(i, j) \) to represent the enhanced pixel value corresponding to \( x(i, j) \), then the adaptive contrast enhancement algorithm can be expressed:

\[ f(i, j) = m_x(i, j) + \frac{D}{\sigma^2_x(i, j)} [x(i, j) - m_x(i, j)] \]  

Where \( D \) is the global mean value, and \( \frac{D}{\sigma^2_x(i, j)} \) is the high frequency partial gain coefficient (CG) which must be smaller than a constant. In this study, we define the constant as MaxCG.

Step 5. Gray level and shape comparison. The suspected defect point's gray level and shape are compared with the horizontal direction positions through horizontal comparison. If there is a big difference, it will be preliminarily determined as the defect point.

Step 6. Defect contrast. Establish a defect library for cable buffer layer from a large number of proven by actual cable defects. The suspected new defect is compared to the defect library. When we find a similar defect, add the defect into the defect library. If we did not find a similar defect, we could compare it with the cable's actual position if conditions permit. After identifying as a defect, we need to add the defect into the defect library to expand the defect library, thus improve the determination accuracy.
3. Example
We get the X-ray image from a cable tunnel. The image's grayscale is 65536, and the gray value is between 0 and 65335. The processing of a typical image is shown in Figure 2. We use eight images to reduce noise and adopt the window width and level to 4000 and 62535. They is set as 1.2, and the MaxCG is set as 15.

(a) Image noise reduction
(b) Adjust the window width and level
Figure 2. The processing of a typical X-ray image of XLPE cable

As shown in Figure 2, the defect can be easily found by naked eyes after using our image processing method. Comparing with the defect library, we can infer that the defect is an ablation hole. Moreover, we also have found many defects, such as the white powdery substance. The main components of white powder are sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>), sodium bicarbonate (NaHCO<sub>3</sub>) and alumina Al<sub>2</sub>O<sub>3</sub> crystals. The white powder exists at cable buffer layer with water blocking structure, aluminum sheath and insulation shielding layer.

4. Conclusion
This study adopts an image processing method for X-ray image detection in high voltage cable. The method includes the image noise reduction, the window width and window level adjustment, the overall contrast enhancement, the local contrast enhancement, the gray level and shape comparison, and the defect contrast. The defect library collected by the old and new defect can expand our ability for defect recognition. According to the defects collected so far, the defects mainly include ablation and white powder.

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