Study on Feature Extraction of Cable Surface Defect Image Based on Morphology and Edge Detection Algorithm

Jing Hu 1,a, Hongyu He 2,b, Guomin Liao 3,c, Guichuan Hu 2,d*

1School of Intelligent Manufacturing, Chongqing College of Architecture and Technology, Chongqing, China
2School of mechanical and power engineering, Chongqing University of science and technology, Chongqing, China
3School of Digital Engineering, Chongqing College of Architecture and Technology, Chongqing, China
aemail: 278252640@qq.com, bemail: 934437763@qq.com, cemail: 1643493318@qq.com, demail: huguichuan@cqust.edu.cn

Abstract. The cable-stayed bridge has been widely used because of its excellent bearing capacity, beautiful structure and relatively low construction cost. As one of the most important mechanical components in long-span cable-stayed bridges, the safety of bridge cables is the focus of attention. The image of cable surface defect was taken as the object, and carrying out the image pretreatment. On the basis, through analysis and comparison, the image of cable crack was processed by morphological gradient operation, meanwhile the Sobel operator was selected to detect the cable surface defect image.

1. Introduction
The cable-stayed bridge has been widely used because of its excellent bearing capacity, beautiful structure and relatively low construction cost. As one of the most important mechanical components in long-span cable-stayed Bridges, the safety of bridge cables is the focus of attention. Due to the complex environment, the load of the cable fluctuates, and there is alternating tensile stress in the live load environment. and the protective layer of its surface will harden, crack, peeling and other phenomena[1]. In addition, the cables have been subjected to wind load and rain erosion in the external environment for a long time, and there are natural disasters such as wind vibration and rain vibration, leading to the extrusion friction of the wires inside the cables, which is prone to corrosion and broken wires.

Firstly, the image pretreatment of cable surface was carried out. Secondly, the basic theory of morphological treatment was analyzed, and the crack was treated by morphological treatment. Finally, the Laplacian operator, Canny operator and Sobel operator were compared, and the surface defect image features were extracted.

2. Defect image preprocessing
In this paper, the image pretreatment of cable surface was carried out by using the methods of gray transformation, threshold segmentation, median filtering to provide a basis for subsequent defect.
The preprocessing process of cable defect image is shown in Figure 1. The first step is Grayscale transformation, the image became a single-channel image which was expressed by grayscale\(^1\). The second step is Threshold segmentation, threshold processing was needed to display the cable surface image features\(^2\). Lastly, Median filtering was used to de-noise the cable surface image.

3. Morphological Operation

3.1 Theory of morphological operation

The main function of morphology is to extract component information, which has great significance for expressing and describing the feature shape of the image. Morphological operation mainly includes: expansion, corrosion, closing operation, opening operation and gradient operation\(^3\).

(1) Expansion and corrosion operation

Two adjacent objects could be connected by expansion operation which expand the image’s boundaries. After image segmentation, there is a blank area between the two adjacent objects, which can be filled by expansion operation. The expression for the corrosion operation is as follows:

\[
A \ominus B = \{ x, y \mid (B)_{xy} \cap A \neq \emptyset \}
\]

(1)

Corrosion is also one of the most basic morphological operations. By shrinking the boundaries of the image, the small and meaningless elements could be removed. In the image processing process, the burr and noise could be cleared by the corrosion operation. The expression for the corrosion operation is as follows:

\[
A \ominus B = \{ x, y \mid (B)_{xy} \subseteq A \}
\]

(2)

(2) Opening and closing operation

Opening and closing operation are just the superposition of two basic operation. In the opening operation, the image is corroded first and then expanded, which mostly used to remove image noise, burr and other operations. In the closing operation, the image is expanded first and then corroded, which mostly used to fill the holes inside, and also connect between different objects. The advantage of opening operation and closing operation is that there will be no geometric distortion in the image processing and the original size of the image target region will be kept.
3. Gradient operation

Gradient operation is a combination of expansion and corrosion operation, through this operation, the edge information of the target image can be obtained. There are four kinds of common gradient operation: basic gradient, internal gradient, external gradient and directional gradient.

3.2 Morphological treatment of crack

Local magnification of the image after median filtering showed that there were still subtle holes and subtle burrs on the cable edge. The main reasons for this phenomenon were the uneven distribution of light source and the vibration of the robot in the working state. These noise points would affect the extraction of defect features, therefore after morphological operation, some holes could be filled, and the line flatness of the cable edge was more regular. The effect of morphological gradient operation is shown in the Figure 2.

4. Defect edge extraction

Due to the complexity of cable defect images, the method of morphological gradient to extract cable surface defects is relatively simple, which is insufficient to meet the requirements of complex working conditions. To solve this problem, it is necessary to further study the algorithm of edge extraction of cable surface defects.

Edge is one of the most basic features of image, it refers to the collection of pixels whose surrounding pixels rapidly change in grayscale. Edge exists between target, background and region, so it is the most important basis for image segmentation. Because of the discontinuity of edge grayscale, the gray value of edge information often changes greatly, and it is easy to observe the step phenomenon of grayscale. Grayscale variation information could reflect the edge features of cable surface image, and in the gradient direction, the grayscale changes fastest, but it is easily disturbed by noise.

4.1 Grayscale gradient function

The grayscale gradient function is the partial derivative of the pixel with respect to the X-axis and Y-axis, and the function value represents the change of the pixel grayscale. The grayscale gradient function of the image has its maximum value at the boundary, therefore, the boundary of cable defects can be determined by finding the maximum value of the gradient function.

The gradient function \( f(x,y) \) of the image at the coordinate point \((x,y)\) is a vector, and defined as follows:

\[
\nabla f(x,y) = \frac{\partial f}{\partial x} \hat{i} + \frac{\partial f}{\partial y} \hat{j}
\]

The amplitude of vector is as follows:

\[
G[\nabla f(x,y)] = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}
\]
4.2 Edge detection operators

Edge detection operator is an operation unit used for edge detection, and different operators have different extraction effects. Several kinds of classical edge detection operators are analyzed\cite{4}.

(1) Laplacian operator

The Laplacian operator is the second derivative operator, because of the property of rotation without deformation, it can meet the requirements of edge detection of images in different directions. For a continuous function \(f(x,y)\), \((x,y)\) represents coordinates in the image. The Laplacian operator is defined as follows:

\[
\nabla^2 f(x,y) = \frac{\partial^2 f}{\partial x^2} \hat{x} + \frac{\partial^2 f}{\partial y^2} \hat{y}
\]  

(5)

(2) Sobel operator

The Sobel operator combines the local average operation with the directional difference operation. Through the horizontal direction and vertical direction edge information calculation, the edge information of two directions could be displayed separately or superimposed. When Sobel operator is used to calculate images with large amount of data, it can effectively reduce the interference of noise on edge extraction because it extracts local edge information in horizontal and vertical directions. With \(f(x,y)\) as the center, the horizontal and vertical partial derivatives are calculated in the field of 3x3:

\[
S_x = [f(x+1,y-1) + 2f(x+1,y) + f(x+1,y+1)] - [f(x-1,y-1) + 2f(x-1,y) + f(x-1,y+1)]
\]  

(6)

\[
S_y = [f(x-1,y+1) + 2f(x,y+1) + f(x+1,y+1)] - [f(x-1,y-1) + 2f(x,y-1) + f(x+1,y-1)]
\]  

(7)

Then the gradient amplitude is as follows:

\[
G[\nabla f(x,y)] = |S_x| + |S_y|
\]  

(8)

(3) Canny operator\cite{5}

The ideal operator of edge detection could not only filter the noise but also keep the integrity of edge information. The Canny operator belongs to this type, and its detection is divided into the following steps:

a. Gaussian filter

Because the edge information of image is easily disturbed by noise, gaussian filter is used to filter it in order to avoid interference. The principle of Gaussian filtering is to carry out the weighted average according to the grayscale value of the pixel and its neighborhood points to be filtered by the Gaussian formula, so as to effectively filter the high frequency noise superimposed in the image.

b. Gradient calculation

The Canny operator is a filter that uses a Gaussian filter to calculate the gradient, and the result is similar to the Sobel operator. It mainly calculates the gradient amplitude \(G\) and direction \(\theta\) in the horizontal and vertical directions, the calculation formula are as follows:

\[
G(x,y) = \sqrt{G_x^2 + G_y^2}
\]  

(9)

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

(10)

c. Non-maximum inhibition

After obtaining the gradient amplitude \(G\) and direction \(\theta\) in the horizontal and vertical directions, the image still has many problems such as edge width and weak edge interference. Therefore, the non-maximum inhibition is needed to find the local maximum value of pixels and clear the grayscale values of other pixels to zero. By this calculation, a large number of non-edge pixels could be eliminated.

d. Double threshold edge connection

After the above three steps, the quality of the edges is already high, but there are still many false edges, therefore, the Canny operator adopts the double threshold algorithm. The specific operation is to select two thresholds: High threshold (maxVal) and Low threshold (minVal), if the grayscale value of the pixel is less than the minVal, it is considered to be a false edge and the grayscale value is cleared to
zero. On the opposite, pixels greater than the maxVal are considered strong edges and the grayscale value is 1. Lastly, link the maxVal pixel edges into Outlines until the entire image is closed.

4.3 Comparison of edge operators

In this paper, the detection capability of various edge detection operators for cable surface defects was compared. A complicated cable wrinkling image is taken as the object, and the Laplacian operator, Canny operator and Sobel operator were used to operate the image. Defect extraction effects of three different operators were shown in the Figure 3.

By comparison, we found that the surface defects extracted by Laplacian operator were relatively fuzzy and the boundary was rough. The image detected by the Canny operator was relatively clear. However, due to the detailed detection of Canny operator, the texture of some complex images would appear too dense and too many surface defect features would be extracted.

For this image, the Sobel operator extraction effect’s clarity was slightly lower than Canny operator, but the distribution rules of the overall cable defect lines were not different from the reality. The computing speed and resource usage of Sobel operator as well as was better than Canny operator. Considering the actual situation, Sobel operator was selected to detect the cable surface defect image, because of the appropriate edge width, good image definition, fast running speed.

5. Conclusion

(1) The image of cable surface defect was taken as the object, and using the Gray Transformation, Threshold Segmentation and Median Filtering for image pretreatment.

(2) Through analysis and experiment, the image of cable crack was processed by morphological gradient operation.

(3) Through the comparison of edge operators, the Sobel operator was selected to detect the cable surface defect image.
Acknowledgments
This paper is from the science and technology research project of Chongqing Education Commission, Research on cable health monitoring system of cable-stayed bridge based on intelligent inspection robot (KJQN201905203).

Reference
[1] Yu Chaoyang. Research on intelligent apparent Detection of cable detection robot[J]. Technology of Highway and Transport. 2020, v.36;No.148(02):90-96.
[2] Li Wenshu. Digital image processing algorithms and applications[M]. Peking University Press, 2012.
[3] Wang Jianlin, Pan Jianping. Research on background Segmentation method of bridge cable surface defect image [J]. Surveying and Mapping Engineering, 2018, 027(007):24-29.
[4] Ma Zonglin. Research on Image Edge Detection Algorithm Based on Digital Morphology [D]. Lanzhou Jiaotong University. 2020,4.
[5] Liu Lixia. Remote Sensing Image Segmentation Based on Improved Canny Edge Detection [J]. Computer Engineering and Applications. 2019,55(12):54-58.