

# Identification Method of Railway Insulator Based on Edge Features

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**Abstract.** Automatic detection and identification of insulators from the image is an important prerequisite for their state detection. In this paper, an insulator recognition algorithm based on Sobel edge feature and SURF algorithm is proposed. The algorithm firstly extracts image edge features, then uses SURF algorithm to extract feature points on edge, and uses Haar wavelet to describe feature points, and uses Euclidean distance to match the detected feature points. Finally, the MSAC algorithm is used to eliminate the error matching caused by noise and other disturbances, so as to realize the intelligent identification of the insulators in the catenary. The experimental results show that the proposed algorithm can accurately identify insulators from target images, which provides a feasible reference for visual identification and positioning of insulators in the intelligent detection system of catenary insulator of electrified railway.

## 1. Introduction

The catenary insulator is an important component in the power supply system of electrified railway. The operation state of the insulator installed on the bracket through the wrist arm affects the safety of the power supply system of the train. The insulators of the catenary are exposed to outdoor environment all the year round and are affected by various environmental factors. The surface of the insulators is liable to form dirt, resulting in the deterioration of insulation performance. After being affected by wet environments such as rain or snow, pollution flashover may also occur. Thus, the safe operation of railway power supply system will be greatly affected. With the wide application of computer image processing technology, it has become a new development trend to use image processing technology to detect the status of catenary insulators. In the power system, there are relatively many researches on the use of image processing technology for insulators. The glass insulators are extracted by using the genetic algorithm and the maximum entropy threshold method. The glass insulators can be effectively identified by using the color statistics and edge chain code features, and the edge histogram can be used to extract the texture features to realize the insulators recognition [1~3]. Currently, there are relatively few researches on contactless image detection for the contact network system. Using the combination of the HOG feature and the SVM classifier can realize the identification of the contact network insulators; the use of the insulators' color features and relative positional relationship can realize the identification of insulators; using Randon and curved wave transform can achieve precise positioning of insulators [4~6].



Insulator recognition belongs to computer vision and pattern recognition. Image matching algorithms are mainly studied from three aspects: transform domain, gray level and feature. The first two algorithms are time-consuming and low real-time due to the use of image global information to match. Therefore, the matching algorithm based on local features has been widely studied. This algorithm is mainly used to extract the important features of the image, such as points, lines, surfaces and so on, which can greatly reduce the computational cost and are widely used [7]. At present, most of the research is focused on point features. Image feature extraction algorithms include Harris operator, SUSAN operator, FAST operator, SIFT operator, and SURF operator [8-10]. SURF algorithm is a kind of image matching algorithm proposed by Herbert Bay in 2006. This algorithm is based on the improved SURF algorithm based on the SIFT algorithm. The algorithm has strong robustness and higher speed than SIFT, and its comprehensive performance is better than that of SIFT algorithm. Many advantages of the algorithm are due to its proper simplification and approximation.

In view of the problem of identifying insulators during railway inspection, a new image recognition algorithm for insulators is proposed in this paper. The shape of insulators is similar, and the insulators can be identified by using the feature points on the edge of the insulator. When the traditional SURF algorithm extracts fewer feature points, it effectively improves the number of feature points detection and reduces the matching time of feature points. The MASC algorithm is used to eliminate the error matching and accurately identify the insulator targets in the image to be measured. It can be used for automatic identification of overhead contact line insulators in railway inspection. It provides a prerequisite for intelligent inspection of catenary insulators in electrified railway.

## 2. The Principle of Recognition of Insulator

### 2.1. The Process of the Detection of the Algorithm

As the type of railway insulator is relatively single and its shape is fixed, the feature points on the edge of insulator image are detected by SURF algorithm, and the feature points of template image and image to be tested are matched. Thus the insulator can be intelligently identified from the inspection image. The specific steps of this algorithm are as follows: detecting image edge features, using SURF algorithm to extract feature points from edge images, and using Harr wavelet to describe the detected feature points, and using Euclidean distance between feature points for initial matching. Finally, MSAC algorithm is used to screen the correct matching points to eliminate the error matching caused by noise and other effects, so as to realize the accurate identification of insulators.

### 2.2. Edge Detection

Edge detection is an important research content in the field of feature extraction. The edge always appears in the form of abrupt change of intensity. The edge of the image contains important information about the shape of the object. The edge detection can greatly reduce the amount of data processing under the premise of preserving the feature structure of the original image, thereby extracting the key feature information of the image.

Edge refers to the set of pixel points that jump in pixel value in the image. Insulator edge images contain contour features of insulators, and the amount of image data is much smaller than that of grayscale. The SURF feature points extracted from the edge image of insulator can reduce part of the computation and improve the efficiency of insulator image recognition. So this paper first extracts the edges of insulators.

The Sobel operator is an edge detection operator based on the first derivative. By using a pixel as the center, the pixel values in the surrounding area are weighted to determine whether it is an extreme value, and the extreme pixel is used as an edge point. The Sobel operator uses the 3x3 template, consisting of two horizontal and vertical templates, as shown in Fig. 1  $G_x$ ,  $G_y$  and  $G(x, y)$  are obtained through convolution of templates and images.

-1	0	1
-2	0	2
-1	0	1

(a) horizontal direction

-1	-2	-1
0	0	0
1	2	1

(b) vertical direction

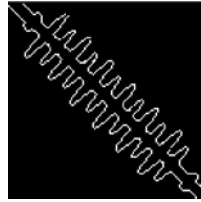
**Figure 1.** Sobel detection operator.

$$G_x = f(x-1, y+1) + 2f(x, y+1) + f(x+1, y+1) - f(x-1, y-1) - 2f(x, y-1) - f(x+1, y-1) \quad (1)$$

$$G_y = f(x+1, y-1) + 2f(x+1, y) + f(x+1, y+1) - f(x-1, y-1) - 2f(x-1, y) - f(x-1, y+1) \quad (2)$$

$$G(x, y) = \sqrt{G_x^2 + G_y^2} \quad (3)$$

For all pixels in the image, a reasonable threshold can be generated, and an edge image can be generated. Fig. 2 is the edge characteristics of insulators.

**Figure 2.** Insulator edge image

### 2.3. SURF Algorithm

The integral image is introduced into the SURF algorithm. Using the integral image, the sum of the gray values in any rectangle of the original image can be easily calculated. The integral image is the same as the original image, but the value B of the integral image at point A is equal to the sum of all the pixels in the rectangular region of the original image which is less than equal to x, and the ordinate is less than equal to the y.

$$I_{\Sigma}(K) = \sum_{i=0}^{i \leq x} \sum_{j=0}^{j \leq y} I(i, j) \quad (4)$$

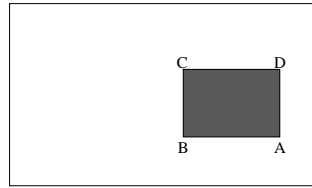
In formula (4),  $I(i, j)$  represents the pixel value of the original image point  $(i, j)$ .

The calculation of the integral image is very easy. It is possible to traverse the original image once to obtain a complete integral image. Using the integral image, it is easy to calculate the sum of gray values in any rectangle within the original image.

The rectangular area in Fig. 3 consists of four points A, B, C, and D. The sum of the gray values in the area is S.

$$S = I_{\Sigma}(A) - I_{\Sigma}(B) - I_{\Sigma}(D) + I_{\Sigma}(C) \quad (5)$$

In formula (5), A is the integral image and S is the sum of the gray values of the rectangular region.



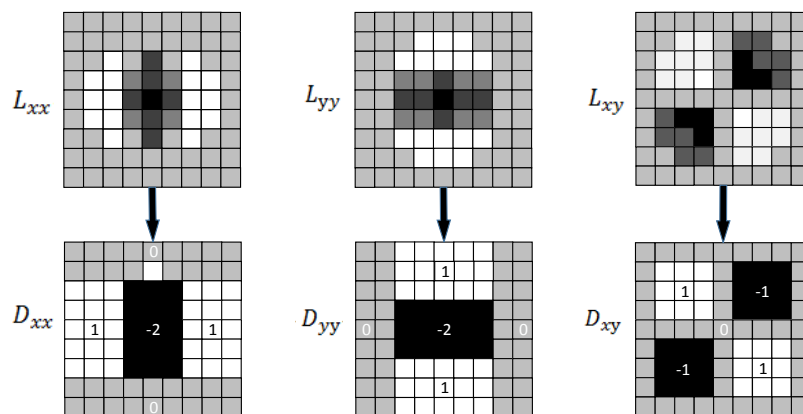
**Figure 3.** Integrate image to calculate the grayscale of rectangular region

Hessian matrix can detect speckle feature points, and guarantee speed and accuracy. For a certain point in the image, the Hessian matrix is:

$$H(X, \sigma) = \begin{bmatrix} L_{xx}(X, \sigma) & L_{xy}(X, \sigma) \\ L_{xy}(X, \sigma) & L_{yy}(X, \sigma) \end{bmatrix} \quad (6)$$

In formula (6),  $L_{xx}(X, \sigma)$  is the convolution of Gauss's two order partial derivative  $\frac{\partial^2 g(\sigma)}{\partial X^2}$  at the point of  $X(x, y)$  and image  $I$ .  $L_{xy}(X, \sigma)$  And  $L_{yy}(X, \sigma)$  have the same meaning.

The SURF algorithm approximated Gauss's two order partial derivative with a box filter. Fig.4 is a discretized Gauss two differential operator and a box filter template for approximating the two order differential operator of Gauss.



**Figure 4.** Box filter approximation

The extreme point of the determinant of the Hessian matrix is the characteristic point. The approximate substitution of the Hessian determinant needs to add weights.

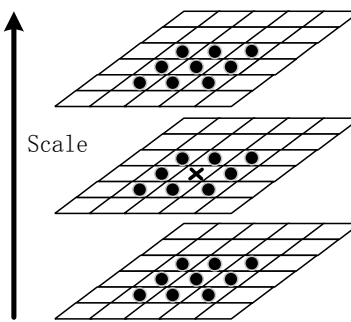
$$Det(H_{approx}) = D_{xx} D_{yy} - (\omega D_{xy})^2 \quad (7)$$

In formula (7),  $\omega$  is the weight value, which is used to balance the error caused by the approximate substitution. Its size is related to  $\sigma$ . In general, it accepts a value of 0.9.

Unlike the SIFT algorithm, in the SURF algorithm, building a scale image depends on a box filter template instead of a Gaussian kernel. When the scale space is established, the size of the cassette filter template is changed on the premise that the size of the original image is invariable, and Hessian matrix response values under different scales can be obtained by using different size box filters, thereby obtaining feature points at different scales.

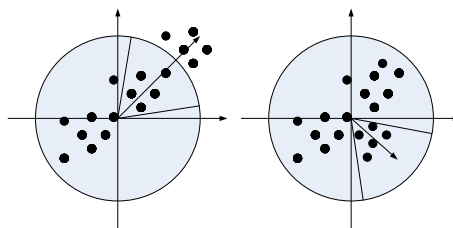
The determination of feature points consists of the following three steps: first, set the threshold and remove the pixels with smaller Hessian determinant values, leaving only the pixels with larger values.

Then, the non-maximum value suppression is carried out, that is, the pixels of each layer are compared with 8 adjacent pixels of the same layer image and the 9 pixels per layer of the upper and lower 2 layers, that is to compare the 3x3x3 neighborhood of each pixel, as shown in Fig.5, if the pixel value is the extreme value, it is the candidate feature point. Finally, the interpolation method is used to improve the positioning accuracy and determine the location of the feature points.



**Figure 5.** Non-maximal inhibition

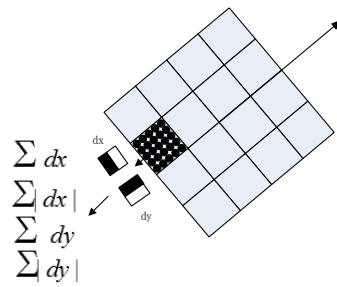
The main direction of the feature points is determined, which helps to keep rotation invariance when the image rotates. First, a circle with a radius  $6s$  is created with the feature point obtained before ( $s$  is the scale value of the feature point), and  $s$  is sampled at the sampling interval to calculate the Harr wavelet response of all the sampled pixels in the circular region. The size of Harr wavelet is  $4s$  and the Gauss function is used to process the response value. Finally, a gradient coordinate system is established by using the Harr wavelet response values in the weighted  $x$  and  $y$  directions to create a  $60^\circ$  fan sliding window, and the sum of the response in the  $x$  direction and the  $y$  direction in the fan area is calculated to obtain a direction vector. After rotating the sector for a week, find the longest vector, and determine the direction of this vector as the main direction of the feature point, as shown in Fig.6.



**Figure 6.** Determining the main direction

The main axis of the feature point is used to rotate the coordinate axis, and a square neighborhood with a side of  $20s$  is constructed with the feature point as the center, and samples are taken at an interval of  $s$ , with a total of 400 sampling points. Dividing the neighborhood into  $4 \times 4$  sub-neighbors, each sub-neighbor has 25 sampling points. The gradients of the  $x$  and  $y$  directions of the sub-neighborhoods are calculated using a Harr wavelet with a size of  $2s$ , and then processed by Gaussian weighting. The values of 25 sampling points are accumulated to form a 4D feature vector, and then 16 subareas share a 64-dimensional feature vector. Use this as a SURF feature descriptor.

$$v = \left[ \sum d_x, \sum d_y, \sum |d_x|, \sum |d_y| \right] \quad (8)$$



**Figure 7.** Feature descriptor generation

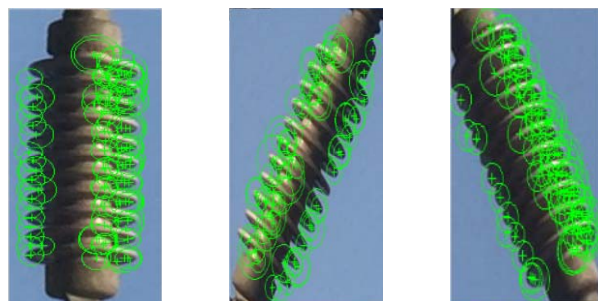
### 3. Identification Process of Insulator

The shape feature of the insulator is fixed, and the feature points are detected by the SURF algorithm. Then the Euclidean distance of the feature vector is used as the similarity measure of the feature points. The method is to obtain the distance from a feature point to the nearest neighbor feature point and the next nearest neighbor feature point. If their ratio is less than the threshold, the matching point pair formed by the feature point and its nearest neighbor feature point is retained. Using this method can eliminate some external points, but there are still some pairs of error matching due to their own and objective reasons. Using MSAC algorithm can effectively eliminate the wrong match, thus completing the identification of insulators [11].

## 4. Experimental Results and Analysis

### 4.1. Feature Point Detection

Fig.8 is an image of the feature point of an insulator template.



(a) template 1      (b) template 2      (c) template 3

**Figure 8.** Feature point extraction

Table 1 lists the number of characteristic points of insulator template and the detection time.

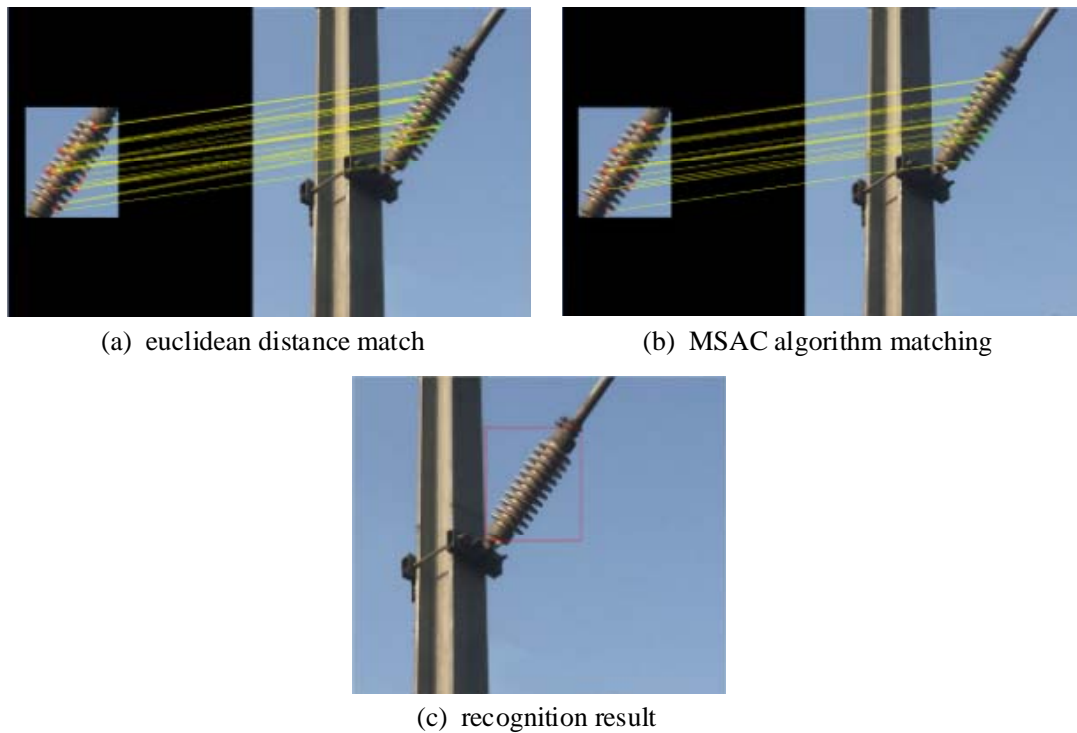
**Table 1.** Feature point detection quantity and time.

Algorithm	Number of feature points	Detection time
template 1	84	0.0804
template 2	76	0.0764
template 3	81	0.0793

### 4.2. Recognition and Matching

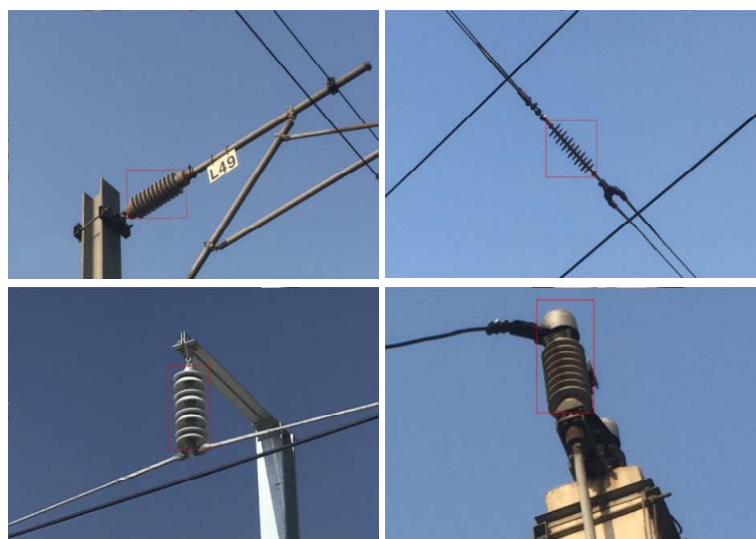
Matching the feature points in the image, and using the MSAC algorithm to eliminate the error matching points, the matching process and results are shown in Fig.9.

(a) Is based on the preliminary matching of Euclidean distance similarity between feature points. It can be seen that there are some pairs of wrong matching points. (b) Shows the effect of using MSAC algorithm to eliminate wrong matching points. (c) Is the final recognition result. The algorithm can accurately identify the insulator target from the image to be measured and mark the insulator in the image with a rectangle.



**Figure 9.** Recognition process of insulator images

Multiple groups of insulators are identified, and the result is Fig.10. It can be seen that the algorithm can accurately identify the insulators present in the target image in different scenarios and mark them.



**Figure 10.** Multiple image recognition results



## 5. Conclusion

This algorithm combines edge feature and fast robustness feature to extract the feature points of insulators, uses Euclidean distance to describe the similarity of feature points, and uses the ratio of nearest neighbor distance to next nearest neighbor distance, and then uses the MSAC algorithm to eliminate error matching points, thus realizing the automatic identification of the insulators in the target image. The experimental results show that the algorithm can accurately identify the insulators from the image to be measured. Furthermore, it provides a feasible reference for the visual recognition and extraction of the intelligent inspection technology for railway insulators.

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## References

- [1] X.N. Huang, Z.L. Zhang, "A Method to Extract Insulator Image from Aerial Image of Helicopter Patrol," *Power System Technology*, vol. 34, issue 1, pp. 194-197, 2010.
- [2] J.C. Lin, J. Han, F.M. Chen, X. Xu, and Y.P. Wang, "Defects Detection of Glass Insulator Based on Color Image," *Power System Technology*, vol. 35, issue 1, pp.127-133, 2011.
- [3] W.G. Li, G.S. Ye, F. Huang, S.K. Wang, and W.Z. Chang, "Recognition of Insulator Based on Developed MPEG-7 Texture Feature," *High Voltage Apparatus*, vol. 46, issue 10, pp. 65-68, 2010.
- [4] Y. Li, "Insulator Location and Recognition Algorithm Based on HOG Characteristics and SVM," *Journal of Transportation Engineering and in information*, vol. 13, issue 4, pp. 53-60, 2015.
- [5] W.W. Lin, B. Deng, L.Y. Yu, W.H. Wu, "Identification Method for Railway Insulator Based on Color and Relevant Reference Feature," *Insulators and Surge Arresters*, issue 6, pp. 40-44, 2016.
- [6] W.X. Wang, Z.G. Liu, M. Su, and G.N. Zhang, "Curvelet Transform based Method for Detection of State of High Speed Railway Insulators," *Electric Railway*, issue 6, pp. 5-8, 2013.
- [7] Y.W. Zhai, "Study on Image Matching Algorithm Based on Improved SIFT," Jilin: Jilin University, 2017.
- [8] Harris C J, Stephens M, "A combined corner and edge detector," *Proceedings of the 4<sup>th</sup> Alive Vision Conference*, UK, pp. 147-151, 1988.
- [9] DAVID G. LOW, "Distinctive image features from scale-invariant key points," *International Journal of Computer Vision*, vol. 60, issue 2, pp. 91-110, 2004.
- [10] Herbert Bay, Andreas Ess, Tinne Tuytelaars, and Luc Van Gool, "Speeded-Up Robust Feature," *Computer Vision and Image Understanding*, vol. 110, issue 3, pp. 346-359, 2008.
- [11] TORR P H S, MURRAY D W, "The development and comparison of robust methods for estimating the fundamental matrix [J].*International Journal of Computer Vision*, vol. 24, issue 3, pp. 271-300, 1997.