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Detecting Technology of Current Generator Blade Shape Based on Improved Canny Algorithm

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Abstract. Aiming at the shortcomings of the image excessively smoothing and the threshold value need to be determined in advance when the Canny algorithm is used for edge detection, an improved Canny algorithm is proposed to detect the blade chord length of the turbine generator. Selecting a proper Gaussian filter coefficient to smooth the original image and remove white noise effects while maintaining the edge information. The image gradient histogram after non-maximum suppression is processed with the Otsu method (the maximum between-class variance method) to adaptively set the high and low threshold. Using the improved canny edge detection method to detect the blade chord length and verify the modified blade. The results show that the hydrodynamic performance of the modified blade has been significantly improved, indicating that the improved canny edge detection algorithm can accurately detect the real edge of the blade, and has a strong self-adaptability. Its detection results are better than the traditional Canny algorithm.

1. Introduction
The theoretical basis of blade design is two-dimensional airfoil theory [1]. The chord length is one of the important parameters of the airfoil external dimensions. Therefore, it has great influence on the power output of the current generator. There are deviations in the blade machining process, which will cause a certain difference between the final chord length and the design scheme. At the same time, the shape of the blade is irregular and three-dimensional, it is difficult to ensure the measurement accuracy by traditional measurement methods. In addition, the size of the blade is large, and the measurement is easily limited by space and equipment. It is an important link and task for the research on the shaping of the current generators blade, at the same time, it is also a prerequisite for large-scale promotion of current generators.

The shape detection technology based on edge detection algorithm is an intelligent detection scheme formed by the intersection of image processing technology and measurement technology, which is with the advantages of fast measurement, accurate measurement and non-contact measurement [2]. The Canny algorithm is an edge detection algorithm that satisfies the optimal criteria. This method has the characteristics of accurate detection, high positioning accuracy, and is widely used in practice. But this algorithm also has shortcomings, such as Gaussian smoothing filter coefficient unreasonable, the high and low thresholds need artificial experience to set and can’t change the parameter value according to the actual content of the image [3]. This paper presents an adaptive edge detection method based on Canny algorithm, which can select appropriate Gaussian filter...
coefficients according to SNR. At the same time, it can adaptively generate high and low thresholds according to the content of the processed image, which improves the insufficiency of the traditional Canny algorithm in edge detection. The flow chart of the current turbine blade chord length measured by the improved canny detection algorithm is as figure 1:

![Flow Chart of Canny Edge Detector Optimization](image)

**Fig. 1** Block diagram of Canny edge detector.

2. Canny edge detector optimization

2.1. Image smoothed by Gaussian filter

The original Canny edge detector includes an image smoothing processing, which convolutes the blade image $I$ with a Gaussian filter as described:

$$G(a,b) = \exp\left(-\frac{a^2 + b^2}{2\sigma^2}\right) \ast I$$

(1)

Where * represents convolution. $G(a,b)$ means intensity of pixel at $(a,b)$ in the image after smoothed. $\sigma$ is the standard deviation of Gaussian distribution[4][5] which is one of the two parameters that needs to be determined in this method. The first-rank parameter $\sigma$ for the proposed method can be automatically decided by the first derivative of SNR, when $dSNR/d\sigma = 0$, get the value of $\sigma$ as shown in figure 2, which indicates that the $\sigma$ equals to 4 when the first derivative of SNR just converges to 0. To account for the effect of Gaussian filter, there is a comparison of images before and after smoothing in figure 3. It can be found that the white Gaussian noise is slightly removed in figure3 (b) compared to figure 3 (a) [6].
2.2. Contrast enhancement

This paper references the first-order gradient template of Sobel operator to calculate the gradient magnitude of the image and expand it to first-order gradient template in four directions: horizontal, vertical, 45°, and 135° [7], as shown in Figure 4.

![Gradient templates direction](image)

**Figure 4** Gradient templates direction (a). the x axis direction (b). the y axis direction (c) the 45° direction(d) the 135° direction

The component of the first-order gradient in the four directions is \( G_x(x, y) \), \( G_y(x, y) \), \( G_{45^\circ}(x, y) \) and \( G_{135^\circ}(x, y) \). Gradient amplitude and gradient direction at point \((x, y)\) can be obtained from one-degree gradient component in the four directions

\[
M(x, y) = \sqrt{G_x^2 + G_y^2 + G_{45^\circ}^2 + G_{135^\circ}^2}
\]

\[
\theta(x, y) = \arctan \left( \frac{G_{45^\circ}(x, y)}{G_x(x, y)} \right)
\]
Inhibit the amplitude of all non-roof band peaks on the gradient line to refine the gradient amplitude in the edge intensity. If the gradient amplitude at point \((x, y)\) on the image is smaller than the gradient amplitude of two adjacent pixels along the gradient line, the pixel is considered as non-Edge point, set to 0.

Figure 5 shows the result of the smoothed blade image in figure 3 after contrast enhancement. Obviously, the blade edge can be visually found from the images, and the contrast between edge pixels and the surroundings is enhanced. The following work is to locate these edge. It is also worth noting that the boundary of the blade and objects in the background are remaining in the blade images. Therefore, another step is required to remove the effects of these boundaries.

![Fig. 5 Representation of smoothed blade edge image after contrast enhancement with the improved canny edge operator.](image)

### 2.3. Thresholds computation based on OTSU

The maximum between-class variance method (Otsu) [8] can automatically select the threshold. This method is based on the histogram and is derived by the least squares method. It has a statistically optimal segmentation threshold. The basic idea is to choose an optimal threshold so that the between-classes obtained with the threshold segmentation have the best separation. The Otsu method has the advantages of strong self-adaptability, good segmentation effect and simple calculation, and it is widely used in image threshold segmentation processing.

For all possible edge points obtained after non-maximal suppression, statistic the gradient information to obtain the edge gradient histogram. The gradient histogram is divided into edge points and non-edge points by setting the threshold value, thereby completing the selection of edge points [9]. The process of selecting a suitable threshold for the gradient histogram segmentation can also be viewed as a classification process of between-class. The theory of adaptive dual-threshold is: according to the characteristics of the gradient histogram, gradient histogram information is firstly divided into absolute and non-absolute edges. The Otsu method is used to obtain an optimal segmentation threshold. And use this threshold to complete the classification of the points which are divided into absolute edges, and locate the absolute edge points as the basis for edge connection. For the gradient histogram of the non-absolute edge part, another segmentation threshold is obtained again using the Otsu method, and this threshold is used as the lowest gradient value of the connection edge. Based on the results of the two obtained segmentation thresholds, the dual-threshold setting in the Canny algorithm can be completed [10]. Assume that the high and low thresholds used for edge detection and connection are \(t_1\) and \(t_2\) respectively, and \(t_1 > t_2\), firstly select the high threshold \(t_1\). According to the result of non-maximal suppression, a gradient histogram \(H(k,l)\) that may be edge points is obtained. Suppose the gradient series of \(H(k,l)\) is \(s\), Then the value range of \(H(k,l)\) is \([0, s - 1]\). Let \(N\) be the total number of points in the gradient histogram. The frequency of gradient value \(m\) in the gradient histogram is \(P_m\)

\[
P_m = \frac{1}{N} \sum_{H(k,l)=m} 1
\]
Based on gradient histograms $H(k,l)$, the gradient threshold $f$ divides $H(k,l)$ into two parts: absolute edge and non-absolute edge.

$$R(k,l) = \begin{cases} 1; & H(k,l) > f \\ 0; & H(k,l) < f \end{cases}$$ (5)

The portion higher than $f$ in the gradient histogram is regarded as absolute edge and the portion lower than $f$ is regarded as possible edge. The ratio of non-absolute edge to gradient histogram is

$$\omega_1 = \sum_{0 < m < f} P(m)$$ (6)

The average of the gradient histogram for the non-absolute edge is

$$\mu = \sum_{0 < m < \omega_1} m \times P(m)$$ (7)

The ratio of absolute edge to gradient histogram is

$$\omega_2 = \sum_{f < m < \omega_1} P(m)$$ (8)

The average of the gradient histogram for the absolute edge portion is

$$\mu_2 = \sum_{f < m < \omega_1} m \times P(m) / \omega_2$$ (9)

The average of gradient histogram is

$$\mu = \sum_{0 < m < \omega_1} m \times P(m)$$ (10)

Then

$$\tau = \text{Max} \left[ \omega_1 (\mu_1 - \mu)^2 + \omega_2 (\mu_2 - \mu)^2 \right]$$ (11)

The value $\tau$ calculated by Equation 11 is the variance between classes. The greater the variance, the greater the probability that the target is separated from the background in the image. When the wrong classification occurs, the variance of the two parts will become smaller, and the probability of wrong division will increase. When $\tau$ obtains the maximum value, the probability that the absolute and non-absolute edges are differentiated in the gradient histogram is the greatest, and the classification effect is the best. Suppose the value in the gradient histogram interval $[0,s-1]$ is $a$, the maximum value is calculated from equation 9, and the high threshold $t_1 = a$ is taken. Select the low threshold $t_2$ on the basis of the high threshold $t_1$. Regard $t_1$ as the bounds, take the first $t_1 - 1$ level of the gradient histogram, and let the gradient histogram be $H_1(k,l)$. So the gradient histogram has the value $[0,t_1 - 1]$, and then apply Otsu method to $H_1(k,l)$ to calculate

$$\tau = \text{Max} \left[ \omega_1 (\mu_1 - \mu)^2 + \omega_2 (\mu_2 - \mu)^2 \right]$$ (12)
Assume that when the value $b$ is taken in the interval $[0, t_1 - 1]$, the value of $\tau$ obtained from the formula is maximum, and the lower threshold $t_2 = b$ is taken at this time.

For all pixels that might be marginal, the following boundary tracking algorithm is adopted. Firstly, take the point where the gradient value is higher than $t_1$, set it as the absolute edge point and the starting point of the edge connection. In the eight-neighbourhood range of the absolute edge point, determine whether there are other absolute edge points, and if there are, connect those as edge. If there is no longer an absolute edge point in the eight-neighbourhood range, then determine if there is a point with a gradient value greater than $t_2$, and if there is, it is also used as an edge connection. When all points in the neighbourhood whose gradient values are greater than $t_2$ are compared, the next absolute edge point is processed. After all the absolute edge points have been disposed, the edge connection process ends. The Otsu method of the image gradient histogram is used to calculate the segmentation thresholds $t_1, t_2$ as the upper and lower thresholds for detecting and connecting edges, in this way, the self-adaptation of the dual-threshold setting is achieved.

2.4. Edge image output and other image processing validation

Figure 6 shows the edge detection results of the improved canny algorithm. Compared with the traditional canny algorithm, the noise is reduced and the edge curve is clearer. From the effect of visual inspection, the edge information of the image obtained by the improved canny algorithm is more obvious, and the pixel difference between the edge feature and the surrounding environment has been significantly improved. In order to verify that the improved canny algorithm performs better than the traditional Canny algorithm for edge processing, edge detection is performed on other images as shown in figure 7. (i) are original images; (ii) are edge maps with the traditional canny edge detector; (iii) are edge maps with the improved canny edge detector.

Fig. 6 The result of blade edge detection
Fig. 7 Edge map results contrast. (i) Original Images. (ii) Edge maps with the traditional canny edge detector. (iii) Edge maps with the improved canny edge detector

3. Verification of the detection scheme

3.1. The blade correction
Compare the chord length obtained from the edge detection with the design curve, get the unacceptable machining accuracy of the blade, and correct the unqualified portion, the result is shown in Figure 8. As can be seen from the figure, the entire chord length change curve is more smooth and continuous after the edge detection correction [11].

Fig. 8 Comparison of chord length before and after correction
3.2. Method validation by detecting hydrodynamic performance.

In order to verify whether the edge detection algorithm method is reliable, this paper analyzes the hydrodynamic performance of the two kinds of blades before and after the detection and correction [12]. The power efficiency coefficients at different tip speed ratios and the lift-to-drag ratio at different attack angle of the optimizing blade and the original blade were tested.

Figure 9 shows the power efficiency coefficient curve of the original blade at different pitch angles. As can be seen from the figure, as the tip speed ratio increases, the turbine’s power efficiency coefficient firstly increases and then decreases. As the pitch angle increases, the turbine’s power efficiency coefficient shows the same change trend. The maximum coefficient appears where pitch angle is 6, and the tip speed ratio is around 6.5. The maximum coefficient is about 0.3, lower than the designed power efficient coefficient 0.35.

Figure 10 shows the curve of the power efficiency coefficient of the Optimizing blade at different pitch angles [13]. From the figure, it can be seen that when the pitch angle is below 9°, the power efficiency coefficient can reach 0.3 or more, and the maximum coefficient is 0.345, appearing at the tip speed ratio of 5.5 and the pitch angle of 6°, which is close to the design power efficient coefficient 0.35.

4. Conclusion

This paper introduces a method for measuring the chord length of the current blade based on the improved Canny edge detection algorithm and validates the reliability. Selecting an appropriate Gaussian filter coefficient to reduce white noise effects, Using the sobel algorithm to extend the gradient template, at the same time, the threshold is adaptively determined using the Otsu method. According to the test results, it can be seen that using the measurement method to detect the edge of the blade can ensure the processing precision of the chord length and improve the hydrodynamic performance of the blade. With the advantages of small error and high precision, it effectively solves the problem that it is difficult to have matching precision measurement tools due to the large size and the irregular shape, and provides the basis for accurate measurement of blade chord length.

In this paper, a current generator blade is used as the specimen, more structures with different shapes should be tested in future. Even though an attempt has been made to complicate the inspection environment with the purpose of simulating the practical testing condition, the on-site test still remains a challenge. In future, with the help of this computer version based blade detection method, the proposed method can be further improved.
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