Rail Defect Edge Detection Based on Improved Canny Operator

Yi-qin CAO and Ye-yu DUAN

School of Software, East China JiaoTong University, Nanchang 330013, China

*Corresponding author

Abstract. In view of the classical Canny operator's susceptibility to noise interference and the inadequacy of noise suppression and detection accuracy in rail image edge detection, an improved Canny operator based edge detection operator is proposed. The improved non-maximum suppression is used to further enhance noise suppression and edge pixel selection. The neighborhood mean Otsu algorithm is used to carry out high and low thresholds. Solve the problem and determine the high and low thresholds adaptively. The simulation results show that the improved algorithm can detect the edge details more perfectly in the rail image edge detection, and can also suppress noise, and has strong adaptability.

Introduction

In image processing, edge information extraction is very important, and the common method is edge detection. Among the commonly used edge detection operators, Canny operator is widely used because of its good edge detection performance.

Canny operator needs to be selected artificially according to prior experience when choosing high or low threshold. However, it is vulnerable to the influence of external factors such as different natural environment and unequal care. It is prone to produce false edges and is susceptible to noise and has no universality. Many scholars have improved the method of threshold selection, which improves the degree of detail protection of image edge to a certain extent. For example, Duan Hong-yan[1] et al proposed that Canny operator should be combined with wavelet transform to enlarge the high frequency coefficients and reduce the low frequency coefficients so as to enhance the image details. However, in the process of wavelet enhancement, evaluation parameters still need to be selected manually, and prior knowledge is still needed in edge detection. Hossain F[2] et al. proposed an adaptive threshold based on mean and median. Contrary to the traditional method, two thresholds are used by lagging. If the gradient amplitude of a pixel is between two thresholds, the undetermined edge points are retained. If the gradient amplitude of a pixel is less than the lower threshold or greater than the upper threshold, the pixel is not an edge pixel. Song R[3] et al. proposed Canny algorithm based on Hough transform. Hough transform is used to connect edges instead of traditional double threshold method. Although this method effectively connects edges, its complexity is relatively high.

In this paper, a Canny edge detection algorithm based on the valley bottom neighborhood mean Otsu is proposed. The improved Canny algorithm is used to detect the rail defects.

Traditional Canny Algorithm and Analysis

Canny edge detection operator was proposed by the scholar John Canny in 1986. It has good edge detection performance and is widely used [4]. The implementation of Canny operator is divided into three steps [5]:

Image Smoothing with Gauss Filter

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Because the orbit image will be affected by objective factors such as natural environment in the acquisition process, resulting in noise interference in subsequent detection, it must be denoised by filtering and so on.[6]

The traditional Canny algorithm uses a Gaussian filter \( G(x, y) \) to process the original image \( f(x, y) \) with a Gaussian smoothing filter, and then obtains the processed image \( g(x, y) \).

The Gauss equation is:

\[
G(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right) \tag{1}
\]

\[
g(x, y) = G(x, y) * f(x, y) \tag{2}
\]

In the above equation, \( \sigma \) is the standard deviation of the Gauss distribution, and * represents the convolution operation.

**Image Gradient Calculation and Non-maximum Suppression**

In smoothed image \( f(x, y) \), the partial derivative of a pixel \((x, y)\) in horizontal direction is \( G_x \), and the vertical partial derivative is \( G_y \), and the gradient magnitude and direction of the pixel are calculated by equation (3) and equation (4).

\[
G_x = \left[ f(x+1, y) - f(x, y) + f(x+1, y+1) - f(x, y+1) \right] / 2 \tag{3}
\]

\[
G_y = \left[ f(x, y+1) - f(x, y) + f(x+1, y+1) - f(x+1, y) \right] / 2 \tag{4}
\]

The gradient magnitude and direction are as follows:

\[
M(x, y) = \sqrt{(G_x)^2 + (G_y)^2} ; \quad \theta(x, y) = \arctan\left(\frac{G_x}{G_y}\right) \tag{5}
\]

Non-maximum suppression is the process of searching for the local maximum of a pixel, which approximates the direction except the four standard gradient directions of \( 0^\circ, 45^\circ, 90^\circ, 135^\circ \). According to the gradient direction, only one maximum gradient value is retained, and the smaller gradient value in the neighborhood in the same direction is discarded directly, thus the edge width is refined to a pixel width.

**Double Threshold Processing**

After the above process, the high-low double threshold method is used to further distinguish edge pixels and connect them to the final edge. It is assumed that any pixel in the undetermined edge point is \( p(i, j, \theta) \), the gradient direction of the pixel is along the standard direction, and the distance \( d(d = 1, 2, 3) \) is the normalized probability. Then the entropy of the image in each direction is:

\[
H(\theta) = \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} p(i, j, \theta) \log_2 p(i, j, \theta) \tag{6}
\]

\( e(\theta) \) represents the mean of entropy and \( d(\theta) \) represents the standard deviation of entropy. High and low thresholds \( T_{\text{high}} \) and \( T_{\text{high}} \) are expressed as:

\[
T_{\text{high}} = \frac{e(\theta)}{3 \times (0.3 + 2d(\theta)))} ; \quad T_{\text{low}} = T_{\text{high}} \times \ln(e(\theta)) \tag{7}
\]
Canny Edge Detection Algorithm Based on Improved VEM

Improved Non-Maximum Suppression

In classical Canny operator, this step is carried out in the four directions of 0°, 45°, 90°, 135° of the pixels to be judged. Because most of the pixels in the image are outside these four directions, the suppression of these pixels is not accurate, and the result of edge detection error is large.

Therefore, this paper proposes an improved method: divide the gradient direction of the neighborhood of the pixel to be judged into four sector areas: 0° ~ 45°, 45° ~ 90°, 90° ~ 135° and 135° ~ 180° (including the symmetrical angle interval of its origin), named as 0, 1, 2 and 3 respectively, as shown in Figure 1.

![Figure 1. Sector gradient direction.](image)

In the image of rail defects, the pixels are discrete two-dimensional matrices. Through interpolation, the pixel values on both sides of the gradient direction of a pixel can be found.

Assuming that the pixels to be judged are \((x, y)\) and the gradient magnitude is \(M(x, y)\), the gradient magnitude of the two neighboring pixels in the gradient direction is \(M(x \pm 1, y \pm 1)\), the two neighboring pixels need to be evaluated by interpolation. By comparing gradient amplitude \(M(x, y)\) with \(M(x \pm 1, y \pm 1)\), the judgment process is completed. If \(M(x, y) \leq M(x \pm 1, y \pm 1)\) means that the neighboring pixel of the pixel in the same direction is not the local maximum, then \(M(x, y) = 0\) is used to suppress the point; otherwise, it means that the pixel is the edge and needs to be preserved.

After this step, some non-edge pixels can be excluded, so that the edge lines are thinner and clearer.

Improvement of Double Threshold Method

Threshold selection method in Canny operator is not suitable for all images, and it needs prior knowledge, so it can not achieve adaptive threshold value. Moreover, the global threshold method has poor effect on the top selection of pixels in different regions of an image. In view of the above shortcomings, this paper improves the threshold selection method, and proposes an Otsu algorithm\(^7\) based on the bottom neighborhood mean to automatically calculate the high and low thresholds of image histogram. The principle of the algorithm is as follows:

Assuming that the gray level of the original image is \(L\) and the pixel value of \(i\) is \(n_i\), the probability of each gray level appearing is:

\[
p_i = \frac{n_i}{\sum_{i=0}^{L-1} n_i}
\]

The image is divided into two kinds of \(C_1 = \{0,1,...,t\}\) and \(C_2 = \{t+1,t+2,...,L-1\}\) according to gray level by threshold \(t\). The probability of occurrence of \(C_1\) and \(C_2\) is respectively:

\[
\omega_h(t) = \sum_{i=0}^{t} p_i
\]

\[(8)\]

\[(9)\]
\[ \omega_2(t) = \sum_{i=t+1}^{L-1} p_i \]

Therefore, the mean values of \( C_1 \) and \( C_2 \) are:

\[ \mu_1(t) = \frac{\sum_{i=0}^{t} ip_i}{\omega_2(t)} \]

\[ \mu_2(t) = \frac{\sum_{i=t+1}^{L-1} ip_i}{\omega_2(t)} \]

The average gray level of the whole image is:

\[ \mu = \sum_{i=0}^{L-1} ip_i \]

The inter-class variance is:

\[ \sigma^2(t) = (1 - p(t))(\omega_1(t)(\mu_1(t) - \mu)^2 + \omega_2(t)(\mu_2(t) - \mu)^2) \]

On the basis of Otsu algorithm, this paper proposes an improved algorithm, which replaces equation (14) with probability mean of neighborhood gray value.

Let the probability mean of image gray level \( t \) in its neighborhood \([-m, m]\) be \( \bar{p}_t \):

\[ \bar{p}_t = \frac{1}{2m+1} \sum_{i=-m}^{m} p_i \]

At this time, the improved inter-class variance is:

\[ \sigma^2(t) = (1 - \bar{p}(t)) \ast \sigma^2(t) \]

Best threshold \( t^* \): When \( \sigma^2(t) \) is the largest, the corresponding \( t \) is the best threshold \( t^* \):

\[ t^* = \arg \max_{0 \leq s \leq L-1} (\sigma^2(t)) \]

Equation (17) calculates the optimal threshold by traversing all gray levels. In order to reduce the operation time of the program, the traversing interval of \( t \) can be set to \([a, b]\). As shown in Figure 2, where \( a \) is the gray level whose probability of the first gray value is not zero and \( b \) is the gray level whose probability of the last gray value is not zero.

![Figure 2](image_url)
In the fourth step of Canny operator, the determination of double threshold edge points is also a process of threshold solution. Through the analysis of gradient image, combined with the selection principle of $T_{high}$ and $T_{low}$ and the analysis of histogram, it is feasible to use the improved Otsu algorithm to realize the selection of $T_{low}$. The improved method further eliminates the regional noise in the image and is conducive to highlighting the threshold so as to obtain the threshold accurately.

Fig. 3 is an image displayed by applying the improved Canny algorithm to the process of rail defect contour edge detection. (a) the result of image segmentation in Chapter 3; (b) the angular image, because the noise has been filtered during image segmentation, does not do the Gaussian smoothing filtering; (c) the amplitude image, it can be seen that the edge of the amplitude image obtained by first-order partial derivative is relatively wide, which is not conducive to highlighting the specific contour of the edge; (d) the non-maximum suppression result image; (e) the final result, compared with (c), the edge outline of the detection is fine and clear enough to detect the edge of rail defects.

**Experimental Results and Analysis**

The experiments are conducted at desktop PC, hardware setting is: Inter Pentium Dual 2.3GHz CPU and 2GB memory, the software is Matlab2014a. The experiment consists of two parts: the first part is the comparison of the results between the proposed method of this paper and two baselines, which include the Otsu calculation method and the Otsu calculation method. The second part is to apply the calculation method to the rail image defect extraction and verify the feasibility of the method.

Through the self-adaptive solution of high and low double thresholds, the image of rail defect edge detection is obtained. The relative gradient amplitude and non-maximum restraint image edge is smaller and the contour is more accurate. The experimental results show that the adaptive Otsu algorithm is helpful to improve the problem of threshold solution in classical Canny operator and get accurate image of edge detection. In this paper, the improved Canny algorithm is used to detect the edge of rail defects, and it is compared with the centralized classical operator introduced earlier.
The edge detection of scar defect, wear defect and crack defect is carried out by the contrast algorithm and the algorithm in this paper. The experimental results are saved as high-definition vector graph. The experimental results are shown in Figure 4.

In Figure 4, (a) the graph is an image to be edge detected, (b) the graph is an improved Canny operator, (c) the graph is a Sobel operator, (d) the graph is a Prewitt operator, (e) the graph is a LoG operator, (f) the graph is a classical Canny operator. From the contrast experiment, the improved Canny operator can detect the details of the defect edge clearly, and the edge is clear. In contrast experiments, (c) Sobel operator detection results are better than other contrast algorithms, but the details of edges are not as much as that of this algorithm, and small edges are often detected as straight lines; (d) Prewitt operator detection edges contain breakpoints; (e) (f) two graphs contain a lot of noise.

Because the binary image of rail defects is simple and the edge detection is easier than the complex image, the effect of edge detection is more demanding. From the contrast experiment, it can be seen that only the improved Canny edge detection operator has no defects, so it can meet the application conditions of the edge detection.

Summary

In this paper, the traditional Canny edge detection algorithm is improved, and an improved Canny operator based edge detection algorithm is proposed. The non-edge pixels are further excluded by the improved non-maximum suppression, considering the pixels in all directions. The high and low thresholds are solved by Otsu algorithm based on the neighborhood mean, which can self-adaptively calculate the thresholds and make the recognition of edge pixels more accurate. The simulation results show that the improved algorithm can detect the edge details more perfectly in the rail image edge detection, and can also suppress noise, and has strong adaptability.

Acknowledgement

The work described in this paper was partially supported by the Foundation of scientific and technological support of Jiangxi Province under the key Grants 20161BBE50081.

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