A Vision-Based Algorithm for Deformation of Steel Pipe Column Detection

Wei-ming SITU¹, Yun-chao TANG²*, Xiang-jun ZOU¹, Wen-xian FENG², Cheng-lin WANG¹, Yu-da MO¹ and Jin-hui LI¹

¹Key Laboratory of Key Technology on Agriculture Machine and Equipment, South China Agriculture University, Guangzhou, China 510642
²Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, China 510006

*Corresponding author

Keywords: Deformation of steel pipe, Edge detection, Canny algorithm.

Abstract. It has great significance for assessing the safety of engineering structures or the bridge by detecting Deformation of steel pipe column. The manual contact measurement is one of the traditional methods to detect the deformation of the steel pipe column. However, in the actual operation environment, the manual contact measurement is difficult and there are some hidden safety problems in the measurement process, thus it is particularly important to study a non-contact measurement method of the steel pipe column. Image processing is one of the common methods of non-contact measurement. In this paper, with the same steel pipe deformation image, respectively, using different edge detection algorithm, comparative analysis of the result, it come to a conclusion that the most suitable algorithm is Canny algorithm, and it is a classic algorithm of edge detection which has been applied in image processing. However, the traditional Canny algorithm has some defects, such as difficulty in threshold setting, low efficiency. Based on traditional Canny algorithm to improve it, this paper proposes an improved custom threshold Canny algorithm. The results show that the method proposed in this paper, the method of which is more than the traditional detection method to save at least 0.8s. Basically meet the requirements of real-time detection of stable and reliable, fast, high accuracy, and has a certain practicality.

Introduction

Steel pipe are widely used in bridges and engineering structures. It inherits the advantages of high bearing capacity, good ductility and convenient construction of the steel pipe confined concrete [1,2], and make up for the low strength, poor ductility and other defects of recycled concrete [3], with good promotion prospects. So the study of detection and evaluation of steel pipe compression deformation has important significance. The traditional detection methods are manual measurement and resistance strain gauge measurements, which are the contact measurement, the steel pipe at the height place is difficult to be detected, so it is very important to study the non-contact measurement method. The camera to obtain images of steel pipe deformation, using image processing technique to measure the deformation of steel pipe is a non-contact measurement method commonly used. The deformation degree of the steel pipe is mainly reflected in the contour, so the image edge is the focus of our research object. Image edge is a very important feature of image processing, it often exists between the target and the background, the target and other target, the region and other region [4]. The accuracy and reliability of the results of image edge detection will directly affect the understanding of the objective world of machine vision system [5]. Therefore, it has been one of the focuses of people to find a kind of edge detection algorithm which has the accurate positioning, anti-noise ability and non-false detection. Edge is often shown in the place of image of the intense gray changes. The target, background and noise edge are often extracted together frequently, therefore, how to distinguish the background, remove the noise, correctly extract the edge of the target is a difficult problem in image
processing. The general steps of image processing are: extracting the original image, graying, filtering, detecting the edge, extracting the characteristic value. Thus the early image filtering is very important for edge detection.

**Edge Detection Algorithm**

Classical edge detection algorithms mainly use the gradient algorithm, the gradient is a metric of function change, and an image can be regarded as a continuous function of the image sampling point array. Therefore, the significant change of the image gray value can be detected by the approximation function of the gradient as one-dimensional case[4]. The simplest gradient algorithm is the Roberts algorithm, and the commonly used algorithm is Prewitt algorithm, Sobel algorithm [6], Laplacian algorithm and Canny algorithm, etc.

**Gradient Algorithm.** Roberts algorithm is one of the simplest gradient algorithm, it is 2 * 2 of the template, using the diagonal direction adjacent to the difference between the two pixels, and it is given by Eq. 1, Eq. 2 and Eq. 3:

\[
\Delta x f = f(x, y) - f(x + 1, y + 1). \tag{1}
\]

\[
\Delta y f = f(x + 1, y) - f(x, y + 1). \tag{2}
\]

\[
R(x, y) = \sqrt{\Delta x^2 f + \Delta y^2 f} \tag{3}
\]

Where \( f(x, y) \), \( f(x + 1, y + 1) \), \( f(x + 1, y) \) and \( f(x, y + 1) \) are the four neighborhood coordinates, \( R(x, y) \) is the output image. Each pixel in the image is used to do convolution with the two kernel.

According to the algorithm formula, it is not difficult to find that it uses the local difference is conducive to the detection of relatively steep edges, but the ability to suppress noise is weak.

**First Order Differential Algorithm.** Sobel algorithm is a differential algorithm, it is 3 * 3 pixel neighborhood template, using gradient value to calculate the gradient of a pixel, and then choose according to a certain threshold, finally get the image edge [7].

![Figure 1. Sobel algorithm template.](image)

From the template we found that Sobel algorithm using weighted average filter, to the edge and non-edge with different weights, restrains noise better than the Roberts algorithm, but at the same time, it reduced the positioning accuracy of edge detection.

Prewitt algorithm is an edge template algorithm, it is 3 * 3 pixel neighborhood template, similar to Sobel method, it also according to a certain threshold choice, finally get the image edges.

The template of the Prewitt algorithm is shown in Figure 2, which is similar to that of the Sobel algorithm, but the edge template is not the same.

![Figure 2. Prewitt algorithm template.](image)
Prewitt algorithm and Sobel algorithm is basically the same, they both use the average filter, which can effectively reduce the noise impact, but the corner of important edge which similar to noise are also be excluded.

**Two Order Differential Algorithm.** Laplacian algorithm is a kind of two order differential algorithm, which has rotation invariance, given by Eq. 4:

\[
\Delta^2 f(x, y) = \frac{\partial^2 f(x, y)}{\partial x^2} + \frac{\partial^2 f(x, y)}{\partial y^2}.
\]  
\[
\Delta^2 f(x, y) = f(x+1, y) + f(x, y + 1) + f(x-1, y) + f(x, y - 1) - 4f(x, y).
\]

In the digital image, the commonly used digital difference approximation, it is given by Eq. 5:

\[
\Delta^2 f(x, y) = f(x+1, y) + f(x-1, y) + f(x, y + 1) + f(x, y - 1) - 4f(x, y).
\]

The corresponding convolution template is shown in Figure 3.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-4</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3. Laplacian algorithm template.

Laplacian operator uses two order differential, which will strengthen the influence of noise, and easy to lose the edge information, making the edge discontinuity, hinder the extraction of edge feature value.

Canny algorithm uses the first derivative of the Gauss filter function, carries on the smooth filter to the image, Gauss filter function is given by Eq. 6 and Eq. 7:

\[
G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}.
\]

\[
g(x, y) = G(x, y) \cdot f(x, y).
\]

Two-dimensional Gauss smoothing function \(G(x, y)\) and image \(f(x, y)\) convolution operation, to get a smooth image \(g(x, y)\).

The gradient of the smoothed image \(g(x, y)\) can be approximated by a 2 * 2 first order difference approximation, as given by Eq. 8 and Eq. 9:

\[
\varphi_1(x, y) = |g(x+y+1) - g(x+y) + g(x+y+1) - g(x+y)|/2.
\]

\[
\varphi_2(x, y) = |g(x+y) - g(x+y+1) + g(x+y) - g(x+y+1)|/2.
\]

The gradient magnitude and the gradient direction of the pixel are as follows:

Gradient Magnitude as given by Eq. 10:

\[
M[x, y] = \sqrt{\varphi_1^2(x, y) + \varphi_2^2(x, y)}.
\]

Gradient Direction as given by Eq. 11:

\[
\theta = \tan^{-1} \frac{\varphi_2(x, y)}{\varphi_1(x, y)}.
\]

In order to accurately capture the edge, need to keep the biggest change points in the local amplitude, the process is called non-maximum suppression. Canny algorithm using a 3*3 template, all the pixels of the gradient amplitude array \(M[i, j]\) to treatment by Gradient amplitude interpolation
along the gradient direction. The template of the center pixel \( m[i, j] \) along the gradient direction of the two values of the interpolation to do comparison, if it is greater than the two magnitudes, \( m[i, j] \) corresponding pixel value is 0, the process is expressed as given by Eq. 12:

\[
m[i, j] = \text{NMS}(M[i, j], \xi[i, j])
\]

Where \( \xi[i, j] \) contain the two gradient magnitude.

Canny algorithm uses a dual threshold algorithm for non-maximum suppression image using two thresholds \( \tau_1 \) and \( \tau_2 \), which can get two threshold edge images \( N_1[i, j] \) and \( N_2[i, j] \). Because image \( N_2[i, j] \) uses a high threshold value, it has a little false edge, but it has many breakpoints. Double threshold method connect the edges to form a contour in the image \( N_2[i, j] \), when reaching the contour endpoints, this algorithm will look for edges can be connected to the contour on image \( N_1[i, j] \) 8 adjacent points. In this way, the algorithm continuously collects the edges in the image \( N_1[i, j] \) until the \( N_2[i, j] \) is connected to a complete image.

Canny algorithm has a strong ability to suppress noise, non-maximum suppression makes the detection of the edge with only a pixel, high positioning accuracy, but its two threshold selection has been a problem.

**Improved Canny Algorithm.** The traditional Canny algorithm has a linear relationship between high threshold and low threshold, the high threshold is generally low threshold of 2 times or 3 times. However, in the practical application, the two threshold to obtain the optimal effect in most cases do not meet such a linear relationship, the image difference of different background is different.

Traditional Canny algorithm gives a reference to the adaptive threshold, but the effect is not very well, commonly used approach is to manually set the threshold.

The traditional threshold setting process is to set the threshold, run the program, observe the effect, close the program, adjust the threshold, repeat the steps in front, and finally get the desired results. The startup and shutdown of the program and adjust the threshold much take a lot of time (at least 1s-2s), therefore the efficiency is low. This paper proposes a fast custom threshold method, in the process of running the program, we can adjust the value of the two threshold of the Canny algorithm in real-time, at the same time, with the change of threshold the edge image will real-time changes.

Specific practices are as follows:

1) Add two slider control, used to adjust the two threshold of Canny algorithm.
2) Drag the slider the threshold will changes, at the same time, the program into a callback function.
3) Callback function contains the edge detection algorithm, the callback function once run, according to the changes of threshold, the image edge will be detected once again, and displayed.
4) When the callback function ended, the threshold was displayed in the box beside the slider.

The edge detection time is very short (about 0.1s-0.2s), and so the custom search process is very simple and have a high efficiency.

**Comparative Analysis of Test Results**

The results of the detection of the steel pipe deformation image using several methods are compared, as shown in Figure. 4.
Roberts algorithm to detect the edge of the image is relatively small, accurate positioning, but contains a lot of noise, because it does not include some smoothing filter, so it is very sensitive to noise. Sobel algorithm uses a weighted average filter, so the noise sensitivity is significantly less than the Roberts algorithm, but there are some false edge and the loss of the target edge, the edge is relatively large, low positioning accuracy. Prewitt algorithm used average filter, can effectively filter the noise, noise inhibition was stronger than that of Sobel algorithm, but corner easily lost, and the detected edge is coarse, cannot get accurate characteristic value. Laplacian algorithm is the two order differential algorithm, double the impact of enhanced noise. Easy to lose the direction of the edge of the steel pipe information, resulting in the edge of the image is not continuous. Canny algorithm is adopted for the Gaussian smoothing filter function to the image smooth processing, so it has strong noise suppression ability and its detection effect is better than other algorithms, the thin edge can be detected, with high positioning accuracy. But the adaptive threshold selection of the traditional Canny algorithm is not good, and the method proposed in this paper is better.

Summary
In this paper, a non-contact measurement method is used to analyze the deformation of the steel pipe. On the comparative analysis of the traditional edge detection algorithm, that Canny algorithm is most suitable for as a steel pipe deformation detection algorithm, in view of the traditional Canny algorithm threshold selection is difficult, regulation low efficiency and other shortcomings, an improved Canny algorithm is proposed. Experiments show that the method presented in this paper is better. Edge detection is an important step in the processing of image. Although many of the current research of edge detection algorithm, without an algorithm that can be universally applied to different images. According to the application requirements, design new algorithms or improved the traditional algorithm comes to better test results is still one of the hot research areas in the future.

Acknowledgements
This work was financially supported by the National Natural Science Foundation of China (No.51578162, 11472084, 51278129), Supported by Science and Technology Planning Project of Guangdong Province, (No.2014A010104011, 2014B090904056), science and technology project of Guangzhou city (No.201510010140), science and technology project of Huizhou city (No.2014B040008006). Corresponding Author: Yunchao Tang.
References


