XICHENG LIU et al: AN ALGORITHM FOR IMPROVED CANNY ADAPTIVE EDGE DETECTION IN IMAGE . . .

An Algorithm for Improved Canny Adaptive Edge Detection in Image Processing

Xicheng Liu*, Jianzhong Xi

School of Electrical Engineering and Information
Southwest Petroleum University
Chengdu, Sichuan, China

Abstract — An edge is one of the most important and basic features in an image. Edge detection is one of the most important research fields in computer vision and is a hot topic in image measurement technology. In this paper, based on the research and analysis of existing edge detection techniques, a new Canny adaptive edge detection method is proposed. This method has the adaptive ability, which can realize edge extraction of the image effectively, and provide accurate information for the following image measurement.

Keywords—Edge detection; image processing; canny operator; adaptive

I. INTRODUCTION

Image measurement technology is a field in the formation of a new measurement technique measure in recent years and is based on optics, involving optoelectronics, computer image science, information processing, computer vision, laser technology and so on many disciplines integrated with modern measuring technology of Sichuan [1]. It is widely used in the measurement of geometrical quantities, airborne remote sensing, micro dimensional measurement of complex parts, and the appearance of three-dimensional detection, and optical interference, stress and strain field. So called, image measurement is the measurement method that can be used to detect and transmit information. The important task of image measurement is to correct the measurement and image processing. When the measurement is made by optical measurement system, computer and image input device, a large number of original images are acquired. The original image is processed by image processing technology, and the edge points of the image are acquired and processed. According to the measurement requirements of the workpiece, the measurement results are calculated, so the image processing technology is the basis and key of the image measurement system [2]. In this paper, based on the research and analysis of the existing edge detection techniques, a new Canny adaptive edge detection method is proposed.

Edge detection is one of the classical problems in image processing. So far, there are many methods and theories, but there is still no universal edge detection algorithm. Therefore, a new edge detection method based on the specific application is proposed, or the existing method is improved to get a satisfactory result, which is still the main direction of the research. The main purpose of this paper is to detect the edge detection in the process of image measurement. In the process of image measurement, the precision, accuracy and speed of edge detection are key indicators of image measurement. For some automatic measuring system, the adaptive ability of edge detection is very important.

II. CANNY CRITERION AND CANNY EDGE DETECTION ALGORITHM

The classical edge detection operator such as Roberts operator, Prewitt operator, Sobel operator, RSCH operator, Place operator and so on are extremely sensitive to noise, which is suitable for the image with less noise and less complexity [3]. In the practical application, the results are not very satisfactory, and the results are not very satisfactory, mainly in the edge blur, the weak edge loss, the whole edge discontinuity and so on. Canny has made a summary of some of the methods and applications of edge detection in the past. On the basis of this, three criteria of edge detection are proposed, which is expressed in the form of mathematics. This chapter mainly introduces the canny criterion and the canny edge detection algorithm.

A. Canny guidelines

(1)The canny principles of edge detection
Canny analysis of the classical edge detection operator and the application of edge detection, found that good edge detection algorithm should have the following three characteristics:
1) Good edge detection performance
Namely, the probability that a true edge point can be judged as a marginal point or a non-edge point.
2) Good positioning performance
That is, the position of the edge point is as close as possible to the center of the true edge. In practical application, it is found that only two of the edge detection algorithm is not good, some edge detection algorithm will have a number of response to the same edge, there will be many edge points, so it needs to add a condition.
3) A single edge response
That each edge point has and only one response, the maximum suppression of the emergence of false edges [4]. These are the three criteria for the canny edge detection. The
theoretical basis of optimal edge detection is set up for the first time, and it is more important to express the three criteria of edge detection. The optimal operator under a given condition can be transformed into a functional optimal problem.

In one dimension case, the finite impulse response of the filter is set up $f(x), x \in [-W, W]$. If the edge curve is detected $G(x)$, and the edge is located $x = 0$, noise is $n(x)$.

1) Good edge detection performance

It is for a good edge detection result should be the real edge point of the non edge point or the non edge point of the probability of the edge points to the lowest, and the signal detection theory, the two probability with the increase of the ratio of the signal to noise ratio, so that a good edge detection performance is equivalent to the detection $f(x)$ of the image at the edge of the signal to noise ratio SNR.

After $f(x)$ filtering, the response of the edge points is:

$$H_n = n_0 \left[ \int_{-\infty}^{\infty} f^2(x)dx \right]^{1/2}$$

The square root of the response of the noise is $H_n = n_0 \left[ \int_{-\infty}^{\infty} n^2(x)dx \right]^{1/2}$

Among them, $n_0$ means square error of noise. So the mathematical expression of the first criterion of Canny is obtained:

$$SNR(f) = \frac{H_n}{H_n} = \frac{\int_{-\infty}^{\infty} G(-x)f(x)dx}{\int_{-\infty}^{\infty} f^2(x)dx}$$

2) Locating criterion

Assuming that the edge location is detected at $x_0$, the actual edge is located $x = 0$, then with $x_0$, $H_n(x) + H_n(x) x_0$ got the maximum, so

$$H_n(0) = 0$$

Since $H_n(x)$ has the maximum value when $x_0 = 0$, so

$$H_n(x_0) = 0$$

So get:

$$H_n(x_0) = H_n(0) + H_n(0)x_0 + 0(x_0) = H_n(0)$$

By (2) and (6) can be obtained:

$$H_n(x_0) x_0 \approx -H_n(x_0)$$

Because,

$$E[H_n(x)^2] = n_0^2 \int_{-\infty}^{\infty} f^2(x)dx$$

So,

$$E[x_0^2] \approx n_0^2 \int_{-\infty}^{\infty} f^2(x)dx$$

$E(x)$ expresses the mathematical expectation of $X$.

The mathematical expression for the second positioning criteria is:

$$Localizati on(f) = \frac{\int_{-\infty}^{\infty} G(-x)f(x)dx}{\int_{-\infty}^{\infty} f^2(x)dx}$$

Among them, $f(x)$ and $G(-x)$, $f(x)$ and $G(-x)$ represents the derivatives of $f(x)$ and $G(-x)$, as $E(x)$ is more small, edge location is more accurate, Canny second criterion is to find the filter function $f(x)$ make Localizati on(f) as large as possible.

The combination of criteria, our goal is to find a filter function $f(x)$, make the following formula reached the maximum,

$$R(f) = \frac{\int_{-\infty}^{\infty} G(-x)f(x)dx}{\int_{-\infty}^{\infty} f^2(x)dx}$$

3) Single edge response criterion

In ideal condition, the filter is used to approximate the length of the filter for the two peak values of the noise response. Since the average distance between two adjacent zero maxima in the output signal is two times the distance of the zero crossing point, the Rice points out that the distance between the two adjacent zero crossing points in the output signal of the function $g$ filter is times that of the zero crossing point:

$$x_{ave} = \pi \left( \frac{-R(0)}{R'(0)} \right)^{1/2}$$

Among them,

$$R(0) = \int_{-\infty}^{\infty} g^2(x)dx$$

$$R'(0) = \int_{-\infty}^{\infty} g'(x)dx$$

So the distance between two adjacent zero crossing points after $f(x)$ filtering is:

$$x_{ave} = \pi \left( \frac{\int_{-\infty}^{\infty} f^2(x)dx}{\int_{-\infty}^{\infty} f'^2(x)dx} \right)^{1/2}$$

The average distance between the maximum values of the edge response of the filter is:

$$x_{max}(f) = 2x_{ave}(f) = kW$$

The Coefficient $k < 1$, $w$ is wave filter $f(x)$ half width.

So in the $2W$ long range, there is a maximum number:

$$N_n = \frac{2W}{x_{max}} = \frac{2W}{kW} = \frac{2}{k}$$

By the upper visible, as long as $k$, then determine the maximum number of values in the $2W$ region. This is the
third rule of Canny. By this criterion, we can ensure that the only response to each edge is obtained by a single pixel wide edge.

If \( f(x) \) meets this criterion. Then by (13) and (14) \( f^* = f(x / w) \) can be obtained to meet this criterion. If \( y \) is proportional to \( w \), for a given \( k \), the results of the third criteria are independent of the spatial scale of \( f(x) \). The mathematical expression of the third criteria will be the problem of finding the optimal filter into a functional optimization problem with constraints.

B. The solution of optimal edge detection filter with canny criterion

Under normal circumstances, the most advantages of functional \( f(f) \) under given constraints (i.e., given \( K \)) are not compact expressions. But it can be discretized by this expression, and then the numerical solution of the second criteria can be written as,

\[
\text{SNR}(f) = \frac{\left| \int_{x'} f(x) dx \right|}{\left| \int_{x'} f^2(x) dx \right|^{1/2}}
\]

The mathematical expression of the second criteria can be written as,

\[
\text{Localization}(f) = \frac{\left| \int_{x'} f(0) dx \right|}{\left| \int_{x'} f^2(x) dx \right|^{1/2}}
\]

For \( f \) to make a scale transformation, so \( f'(x) = f(x / w) \), you can get

\[
\text{SNR}(f') = \sqrt{\text{SNR}(f)}
\]

\[
\text{Localization}(f') = \frac{1}{\sqrt{w}} \text{Localization}(f)
\]

By the upper (20) and (21) the type can be seen that the increase of the width of the filter will improve the image SNR, but will reduce the positioning accuracy, but their product is not changed.

\[
J(f_c) - J(f) = \frac{\left| \int_{x'} f(x) dx \right|}{\left| \int_{x'} f^2(x) dx \right|^{1/2}} \cdot \frac{\left| \int_{x'} f(0) dx \right|}{\left| \int_{x'} f^2(0) dx \right|^{1/2}}
\]

So \( J(f) \) can be simplified as,

\[
J(f) = \frac{\left| \int_{x'} f(x) dx \right|}{\left| \int_{x'} f^2(x) dx \right|^{1/2}} \cdot \int_{x'} f(0) dx
\]

The solution to this problem is not related to the spatial scale, and the Canny is obtained by using the variational method. Optimization problem of functional. The first derivative of the Gauss function can be used to the best approximation, and the use of a Gauss function. The calculation of the second order derivative becomes simple.

In the edge detection of image, the suppression of noise and edge location is contradictory, and the smoothing filter can eliminate the noise of the image, which can cause the edge location of the uncertainty[5].

High and low threshold set on edge detection results great influence, to artificially set the threshold, it is very difficult to obtain the satisfactory effect, is the best compromise between the anti noise interference and the exact location.

III. CANNY ADAPTIVE EDGE DETECTION METHOD

A. The defects of traditional canny algorithm

Canny operator has achieved good results in edge detection, and has achieved a good balance in the image de noising and edge detail preserving. But in practical application, image in shooting, transmission, conversion process subject to the influence of various factors, such as cameras and light pictures of the impact strength, image in presence of noise, the contrast of the whole image of inconsistent and fuzzy edge found. In these cases, the edge detection is carried out with the traditional canny operator, and the following several aspects are present:

1) the traditional Canny operator uses Gauss filter to smooth the image, Gauss filter coefficients need to be determined, and the different Gauss filter coefficients have a great influence on the image edge detection[6]. The man-made filtering coefficient is difficult to achieve the requirements of noise smoothing and edge protection.

2) The gradient amplitude of the traditional canny operator is calculated by the finite difference mean of the neighborhood of 2x2, but it is more sensitive to the noise, and it is easy to detect false edges and missing some real edge details.

3) The traditional canny algorithm level threshold parameter is not determined by the characteristics of the image edge, by artificially set, do not have adaptive ability.

Due to the existence of these problems, the canny algorithm is applied to the practical application [7]. In this paper, we propose a canny adaptive edge detection method to improve the shortcomings of the traditional canny algorithm.

B. An improved gradient calculation method

Aiming at the defects of the traditional Canny algorithm, the paper presents a new method of calculating the gradient of 3×3 neighborhood 3×3 common neighborhood 4 adjacent difference gradient computation expressions are as follows:

\[
f_c(\Delta_0, \Delta_1) = \frac{1}{2} (f_{j+1} - f_{j-1}) \quad f_c(\Delta_0, \Delta_1) = \frac{1}{2} (f_{j+1} + f_{j-1})
\]

The commonly used neighborhood difference method for calculating gradient, rotation invariance is only 90°.
integer times. The two valued image shown in Figure 1, figure 1 (a) is shown by vertical edges, and the gradient amplitude is calculated using (24) type \( \sqrt{v^2 + b^2} = 1/2 \).

But the same edge if the rotating 45°, as shown in Figure 1 (b), in accordance with the (24) formula to calculate the gradient amplitude \( \sqrt{v^2 + b^2} = \sqrt{2}/2 \). That is to say that the original strength of the same two edges, if one is close to the horizontal or vertical, and the other is close to the same value \( 1/2 \). The improved gradient calculation method is stronger than the former.

\[
\sigma = \frac{a + b}{2} \quad \text{or} \quad \sigma = \frac{a - b}{2}
\]

where \( a \) and \( b \) are the gradient values of the texture region image can be expressed as:

\[
\sigma = \frac{a + b}{2}
\]

which is not the Sobel operator. In the edge detection, the use of the commonly used (24) type of computing gradient, there is a clear "bias" inclined edge of the tendency, the improved gradient method to balance the edge of the positioning accuracy and noise suppression requirements.

\[
P_1(g) = \begin{cases} 
\frac{1}{\sqrt{2\pi\sigma^2}} e^{-g^2/2\sigma^2}, & g > 0 \\
0, & g \leq 0
\end{cases}
\]

\[
P_2(g) = \begin{cases} 
\frac{1}{\sqrt{2\pi\sigma^2}} e^{-g^2/2\sigma^2}, & g > 0 \\
0, & g \leq 0
\end{cases}
\]

The establishment of the model of image gradient classification:

\[
F(x, y) = f_x / \sigma_x, \quad x = f_y / \sigma_y
\]

Will be subject to N (0, 1) distribution. According to the basic theorem of probability theory:

\[
y = x^2 + y^2 = (f_x^2 + f_y^2) / \sigma^2
\]

Then the \( x^2 \) will be subject to the \( Y \) distribution of 2 degrees of freedom, and the probability density function is:

\[
p_x (y) = \frac{1}{\sqrt{y}} e^{-y/2}, \quad y > 0
\]

From this, the probability density function of the gradient mode value of the edge region is

\[
g = (f_x^2 + f_y^2)^{1/2} = \sigma \sqrt{y}:
\]

\[
y = g^2 / \sigma^2 \Rightarrow \frac{dy}{dg} = 2g / \sigma^2 \Rightarrow p_y (g) = \frac{1}{\sigma^2} e^{-g^2/2\sigma^2}, g > 0
\]

Where \( \sigma_x \) represents the variance of the first derivative of the image edge.

In the same way, the probability density function of the gradient values of the texture region image can be expressed as:

\[
p_1(g) = \begin{cases} 
\frac{1}{\sqrt{2\pi\sigma^2}} e^{-g^2/2\sigma^2}, & g > 0 \\
0, & g \leq 0
\end{cases}
\]

The variance of the first order derivative of the image texture in the formula \( \sigma^2 \).

If the prior probability of the "edge" pixels in a given image is \( P \), the prior probability of the "texture class" is \( 1 - P \), so the mixed probability density function of the gradient mode of the image can be expressed as:

\[
p(g) = P p_1(g) + (1 - P) p_2(g)
\]
For a given gradient mode value \( g \), it belongs to the posterior probability of the edge class:

\[
Pr_e(g) = \frac{P_e(g)}{P_e(g) + P_t(g)} = \frac{\exp\left(\frac{(g - \sigma_e^2)}{2\sigma_t^2}\right)}{1 + \exp\left(\frac{(g - \sigma_e^2)}{2\sigma_t^2}\right)}
\]  

(35)

Among them,

\[
L(g) = Pr_e(g) = \frac{\exp\left(\frac{-(g - \sigma_e^2)}{2\sigma_t^2}\right)}{1 + \exp\left(\frac{-(g - \sigma_e^2)}{2\sigma_t^2}\right)}
\]

(36)

\( L(g) \) is called the likelihood ratio. Since \( \sigma_e \) and \( \sigma_t \) are respectively represented by the image edge, the variance of the first derivative of the first derivative and the variance of the first derivative of the image texture, Thus \( \sigma_e > \sigma_t, g \geq 0 \), so \( L \) is a monotonically increasing function of \( G \). And \( Pr_e(g) \) is a monotonically increasing function of \( L(g) \). So \( Pr_e(g) \) is a monotonically increasing function of \( G \). The minimum value of \( Pr_e(g) \) is:

\[
Pr_e(\min) = Pr_e(0) = \frac{P_e(0)}{P_e(0) + (1 - P_e(0))}
\]

(37)

While the maximum value of \( Pr_e(g) \) is determined by the maximum gradient mode \( g_{\max} \), i.e.,

\[
Pr_e(\max) = Pr_e(g_{\max}) = \frac{L(g_{\max})}{1 + L(g_{\max})}
\]

(38)

In order to verify the rationality and universality of the image gradient probability model, we randomly selected the natural images of 10256x256x8bi pixels, and the reduction is shown in Figure 3. Parameter estimation of them respectively according to the algorithm of this paper. The parameters used in the experiment are \( N = 100 ; \eta = 0.1 \), the initialization parameter is: \( \left(MSE^{(0)} - MSE^{(i)}\right) / MSE^{(0)} < 10^{-6} \)

\( \rho^{(0)} = 0.3, \sigma_e^{(0)} = 0.7, \sigma_t^{(0)} = 0.1, \delta_e^{(0)} = 100 \)

Iterative termination condition: Iterative step size \( 0.05 \).

**Table 1. Parameters and fitting error results.**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Parameter estimation ( P )</th>
<th>Parameter estimation ( \sigma_e )</th>
<th>Parameter estimation ( \sigma_t )</th>
<th>Fitting error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5329</td>
<td>0.1702</td>
<td>0.0354</td>
<td>0.0021</td>
</tr>
<tr>
<td>2</td>
<td>0.3010</td>
<td>0.6889</td>
<td>0.0329</td>
<td>0.0094</td>
</tr>
<tr>
<td>3</td>
<td>0.3121</td>
<td>0.6009</td>
<td>0.0310</td>
<td>0.0062</td>
</tr>
<tr>
<td>4</td>
<td>0.6201</td>
<td>0.2109</td>
<td>0.0465</td>
<td>0.0013</td>
</tr>
<tr>
<td>5</td>
<td>0.6218</td>
<td>0.1367</td>
<td>0.0326</td>
<td>0.0013</td>
</tr>
<tr>
<td>6</td>
<td>0.4026</td>
<td>0.6871</td>
<td>0.0274</td>
<td>0.0057</td>
</tr>
<tr>
<td>7</td>
<td>0.6001</td>
<td>0.1402</td>
<td>0.0269</td>
<td>0.0036</td>
</tr>
<tr>
<td>8</td>
<td>0.7148</td>
<td>0.2901</td>
<td>0.0688</td>
<td>0.0021</td>
</tr>
<tr>
<td>9</td>
<td>0.3720</td>
<td>0.6870</td>
<td>0.0392</td>
<td>0.0033</td>
</tr>
<tr>
<td>10</td>
<td>0.6410</td>
<td>0.1301</td>
<td>0.0284</td>
<td>0.0026</td>
</tr>
</tbody>
</table>

In this paper, the parameters of the gradient probability model are listed in Table 1. From the table, we can see that the parameters of the mixed probability density function are consistent with that of the image [10]. For example, the "edge class" prior probability \( P \) of sample image 2 and 4 is about 1/3, which indicates that there are a lot of "flat", while the sample is 3 and 7, while \( P \) is about 60%. This numerical difference can be verified by the observation of the image. The mean square error of the fitting is below 1%, which shows that the image gradient probability model is established for most natural images.

As can be seen from the table, the distribution of the image gradient can be considered as random events, the image gradient probability model can accurately describe the image gradient in the "edge" and "texture" distribution rule, automatically select the appropriate level of threshold, improve the algorithm's automation degree and accuracy.

**IV. Results**

In this paper, based on the advantages of the traditional canny algorithm, the adaptive canny algorithm has been developed to monitor more edge details, and to get a better edge image, the ability of monitoring the edge is better than
the traditional canny algorithm. The threshold of the traditional canny algorithm needs to be set artificially, and the canny adaptive algorithm can automatically generate the appropriate high and low threshold, which is based on the different characteristics of the image edge, and the automatic Chengdu is high, and the effective edge is better preserved. Thus, canny adaptive edge detection method is an effective method.

V. DISCUSSIONS

Edge is the most basic feature of image, image segmentation is the important basis, image analysis and image understanding and other high-level processing of the key edge feature extraction is a successful image measurement, image retrieval, image encoding, image how to more accurate, better detection of the image edge has its important significance and good application prospect of the proposed Canny adaptive algorithm, which has a certain ability to promote high level processing. Applying it to the practical application, it has very important significance for image measurement and image reconstruction based on the edge of image and image reconstruction of encoding. Provide an important reference for the follow-up treatment.

VI. CONCLUSION

Image edge detection is always a hot spot in the research of image measurement technology[11]. It has important applications in image segmentation, pattern recognition, machine vision, image retrieval and other fields. With the development and application of the research in recent years, many new theories and methods of edge detection have been produced. However, due to the complexity of the objective world, it is difficult to detect the complete edge of the target in some specific cases. In this paper, some basic requirements of image measuring system for edge detection are discussed, and some methods of edge detection are analyzed and studied. The algorithm of Canny edge detection is discussed. Based on this, the adaptive edge detection method based on Canny is proposed. This method has adaptive ability. It can effectively realize the image edge extraction and provide accurate information for the following image measurement.

REFERENCES