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A New Sub-pixel Edge Detection Method of Color Images

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Abstract

Modern image measurement needs to take full advantage of sub-pixel edge information of images. This paper presents a sub-pixel edge detection method of color images based on image dimensionality reduction and the least square method. First of all we get the pixel level edge by Ostu algorithm and then combine gray processing algorithm based on color spatial distance and the least square method for sub-pixel edge location. Experimental results show that the algorithm positioning accuracy can reach 0.13 pixel which provides a basis for the selection of color image sub-pixel edge positioning.

***Keywords**: threshold selection, dimensionality reduction, the least square method, color image*

1. Introduction

Color image provides more and richer visual perception than grayscale images. At present the edge positioning accuracy of gray-scale images has reached the sub-pixel level which incudes fitting [1, 2] interpolation method [3-5] moment method [6, 7] and so on but the edge detection techniques of color images are just staying at the pixel level mainly including vector approach [8, 9] the output fusion method [10] multi-dimensional gradient method [11]. With the increasingly widespread use of color images and the actual application requirements the sub-pixel edge localization of color images is taken more and more attention.

According to the imaging principle of the color image we realize the dimension reduction of images [12-15] based on color spatial distance then combine ostu algorithm and the least squares method to extract sub-pixel edges of color images. The algorithm takes full advantage of the color feature information of images which to some extent improves the sub-pixel edge positioning accuracy.

2. Algorithm

2.1. Color Image Dimensionality Reduction

In the process of image processing the color of the pixel usually takes the three primary colors of RGB space which tend to have very strong correlation among them so it leads to lower precision of edge detection. In order to remove the correlation among the three components and reduce the complexity of the operation this paper presents an improved gray processing algorithm based on color spatial distance.

For a color image the object edge pixels have the largest second moment in their neighborhoods the change of second moment is caused by the differences between the brightness of the object and the background luminance. Therefore the steps of gray processing algorithm based on color spatial distance are as follows:

Step 1: Calculate the average Avg_R、Avg_B、Avg_B of R G B three components of all pixels in the color image.

Step 2: Calculate the standard deviation Dec_R、Dec_G、Dec_B of R G B components in the color image.

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Step 3: Compute gray weighted coefficient Co_R、Co_G、Co_B of R G B components and weight coefficient Wc_R、Wc_G、Wc_B.

Step 4: Calculate the threshold of the color image $dThreshhold = Dec_R \times Co_R + Dec_G \times Co_G + Dec_B \times Co_B$

Step 5: Calculate the distance from the gray value to its corresponding average. $dDist = Dist_R + Dist_G + Dist_B$

Step 6: According to the magnitude relation between $dDist$ and $dThreshhold$ to get projection values of each pixel. If $dDist \geq dThreshhold$ the projection value of the corresponding pixel is:

$Gray = d\,\mathrm{Re}\,d \times Wc_R \times 0.299 + dGreen \times Wc_G \times 0.587 + \times dBlue \times Wc_B \times 0.114$.

Otherwise, $Gray = [1/3, 1/3, 1/3] \times [R, G, B]^T$.

It should be noted that when to go on weighted processing for partial pixels of image if we use the weighted formula directly the gray value of the image will become very small and very dark which will destroy the edge structure. Therefore when processing the image we can remove the gray coefficient so the formular changes to be $Gray = d\,\mathrm{Re}\,d \times W_{CR} + dGre\,\mathrm{en} \times W_{CG} + dBlue \times W_{CB}$. For the pixels which do not need to go to weighted processing we can realize gray processing using the average value method. Through the above improvements increase asymmetry of image brightness distribution so that the edge structure is well preserved and the edge stand out. experimental results show that the method is effective to keep the edge information of the image and a good effect is obtained in practical application.

2.2. Ostu Method for Image Coarse Positioning

The Ostu method is based on the principle of least square method it is a binarization method of automatically selected threshold its basic idea is to divide the image into two groups by using a pixel value when the two groups have the maximum variance the value can be the threshold of binarization processing.

Assume the gray value range of an image is $0 \sim L$ the number of pixels whose gray value is i is n_i the total number of pixels is N the appearance probability of pixels whose gray value is i is P_i so:

$$N = \sum_{i=1}^{L} n_i \tag{1}$$

$$P_i = n_i / N \tag{2}$$

According to the threshold T the pixels in the image are divided into two categories μ_0 is the target area mean whose gray level is lower than T and μ_1 is the background region mean whose gray level is higher than the threshold T thereby we can obtain the following equation:

$$\mu_0 = \sum_{i=T}^{T} iP_i / w_0 \qquad \mu_1 = \sum_{i=T}^{L} iP_i / w_1 \tag{3}$$

Where w_0 and w_1 are respectively the probability of target area and the background area that:

$$w_0 = \sum_{i=0}^{T} P_i \qquad w_1 = \sum_{i=T+1}^{L} P_i = 1 - w_0 \tag{4}$$

Then the average of the whole image:

$$\mu = w_0\mu_0 + w_1\mu_1 \tag{5}$$

According to the theory of pattern recognition, we can obtain between-class variance value and within-class variance value respectively:

$$\begin{aligned} \sigma_B^2 &= w_0 w_1 \left(\mu_0 - \mu_1\right)^2 = w_0\left(\mu_0 - \mu_T\right)^2 + w_1\left(\mu_1 - \mu_T\right)^2 \\ s_w^2 &= w_0 s_0^2 + w_1 s_1^2 \end{aligned} \tag{6}$$

Among which:

$$\begin{aligned} \sigma_0^2 &= \sum_{\mathrm{i}=t}^{T}\left(i-\mu_0\right)^2 P_i / w_0 \\ \sigma_1^2\left(\mathrm{t}\right) &= \sum_{\mathrm{i}=t}^{T}\left(i\mu_1\left(t\right)\right)^2 P_i / w_1\left(t\right) \end{aligned} \tag{7}$$

To search each gray value according to a certain order in the whole grayscale range the process of ${\sigma_B}^2$ maximizing and minimizing ${\sigma_B}^2$ is essentially the process of automatically select threshold. Ostu method determine the optimal threshold value T by maximizing one of the following formula:

$$\lambda = \frac{\sigma_B^2}{\sigma_w^2} \qquad K = \frac{\sigma_T^2}{\sigma_w^2} \qquad \eta = \frac{\sigma_B^2}{\sigma_T^2} \tag{8}$$

2.3. Least Square Method

The least square method is an optimal estimation technology derived by the maximum likelihood method when the random error meet normal distribution which enables the sum of the squares of the measurement errors reach the smallest so it is considered as one of the most reliable method to get a set of unknown parameters from a group of measurements. For a given image the difference value of object is maximum at the edge which is the classical principle of edge extraction. According to the central limit theorem the grey value change of edges should be a gaussian distribution.

The expression of gaussian curve is $y = \frac{1}{\sqrt{2\pi}\sigma}\exp(\frac{-(x-\mu)^2}{2\sigma^2})$ where μ is the average σ is the standard deviation .We use gaussian curve to do some transformation logarithm on both sides then we can get the following formula:

$$\ln y = -\frac{(x-\mu)^2}{2\sigma^2} + \ln\frac{1}{\sqrt{2\pi}\sigma} \tag{9}$$

As can be seen the above equation is quadratic curve about x so we can use logarithmic values to fit the parabola and then find the vertex coordinates so the computation is greatly simplified.

The curve equation which is used to fit edge signal is $y = ax^2 + bx + c$ we can obtain the values of a b c by the least square method so that tne sum of square errors can be the minimum.

$$S = \sum_{i=1}^{n}(\mathrm{y}_i - \mathrm{ax}_i - \mathrm{bx}_i - c)^2 \tag{10}$$

Caculate the partial derivatives of a b crespectively and make the values of partial differentives be 0 then we can get that:

$$\begin{cases} a = \dfrac{d \times e - f \times g}{h \times d - g \times g} \\ b = \dfrac{f - g \times a}{d} \\ c = \dfrac{1}{n}(\sum_{i=1}^{n} y_i - \mathrm{a} \times \sum_{i=1}^{n} x_i^2 - b \times \sum_{i=1}^{n} x_i) \end{cases} \tag{11}$$

Among which:

$$\begin{cases} d = n\sum_{i=1}^{n} x_i^2 - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i \\ e = n\sum_{i=1}^{n} x_i^2 y_i - \sum_{i=1}^{n} x_i^2 \sum_{i=1}^{n} y_i \\ f = n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i \\ g = n\sum_{i=1}^{n} x_i^3 - \sum_{i=1}^{n} x_i^2 \sum_{i=1}^{n} x_i \\ h = n\sum_{i=1}^{n} x_i^4 - \sum_{i=1}^{n} x_i^2 \sum_{i=1}^{n} x_i^2 \end{cases} \tag{12}$$

It should be noted that the above-obtained solution is obtained by the logarithm of the original Gaussian curve. In another word the value of a pixel after logarithm in accordance with the quadratic curve so the pixel gray values in the formula should be insteaded by the logarithm values thus get the values of μ and σ :

$$\begin{cases} \mu = -b/(2 \times \mathrm{a}) \\ \sigma = \sqrt{\dfrac{-1}{2 \times a}} \end{cases} \tag{13}$$

The value of μ is the sub-pixel value.

Due to the image has the rotation invariant at the same dege and as a result there is no special requirements for select straight direction when calculates the subpixel coordinates any direction will be OK.

2.4. Steps of the Algorithm

The main idea of this algorithm is that use Ostu method to obtain all possible edge points of pixel level firstly and then use gray processing algorithm based on color spatial distance to reduce the dimensions of the image and finally on the projected image use the pixel level edge points which have been obtained to realize sub-pixel edge location combining the least square method. The flow chart of sub-pixel edge detection algorithm of color image presented in the paper are is follows:

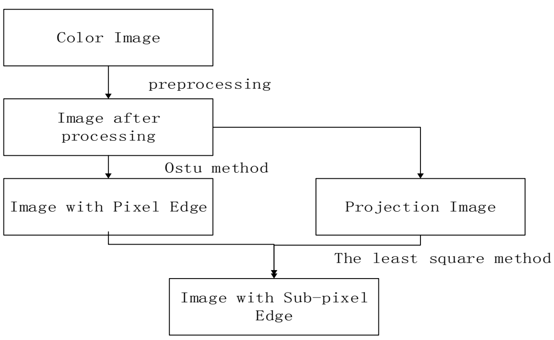

Figure 1. The Flow Chart of Sub-pixel Edge Detection of Color Images

3. Experiment and Result Analysis

Evaluation criteria for subpixel algorithm is to consider the precision of the algorithm the precision of the algorithm itself must use the ideal image to evaluate so that it can eliminate the influence of noise we cannot obtain images by cameras because the image parameters can not be determined leading to the reference is not accurate and the image obtained by the cameras will inevitably introduce noise. Therefore we use computer to generate a standard image by simulating the actual imaging process and we take it as the basis of test localization accuracy of localization algorithm. As shown in Figure 2 use CCD imaging principle to simulate color standard linear images whose slopes k are respectively 0,1, 2, 4.

(a) k=0 (b) k=1 (c) k=2 (d) k=4

Figure 2. Standard Color Line Images

Calculate the average distance btween the sub-pixel edge obtained by the proposed algorithm and the actual sub-pixel edge which is the positioning accuracy of the image. The expression of positioning accuracy is:

$$m = \frac{\sum_{i=1}^{n} d_i}{n} \quad (14)$$

Where d_i is the distance between the detected edge position of the sub-pixel and the actual sub-pixel edge n is the number of detected edge points.

Positioning accuracy is shown in Figure 3 among them the dotted line is the positioning accuracy of traditional algorithm and the solid line is the sub-pixel location accuracy using the proposed algorithm which firstly minimize converts color image to projection image and then use the least square method to realize subpixel edge location. Experimental results show that the highest positioning accuracy of the proposed algorithm can reach 0.13 pixels while the maximum precision of traditional algorithm is just 0.2 pixels. Thus the proposed algorithm makes full use of characteristic information of color images so that it improves the image of subpixel edge location accuracy.

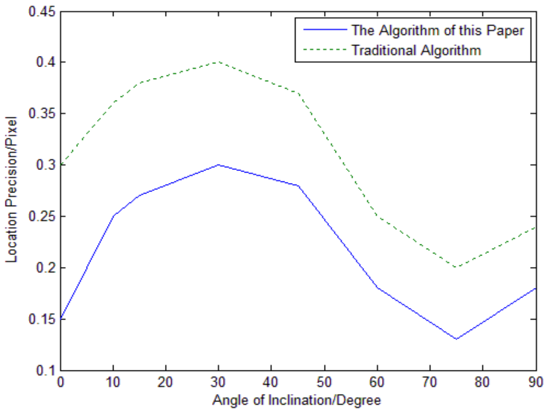

Figure 3. The Location Accuracy Comparison Chart

In order to verify the proposed algorithm we selected tea service image in the experiment as shown in Figure 4 and we did a comparison between the proposed algorithm and traditional algorithm. Among which The Figure 4(a) is the original image Figure 4(b) is the sub-pixel edge image obtained by traditional algorithm and Figure 4(c) is the sub-pixel image got by the proposed algorithm. Experimental results show that the proposed algorithm can obtain a more accurate subpixel edge compared with traditional algorithm the latter exists discontinuities it is because the traditional algorithm uses a specific formula for color image gray processing thereby ignore the color characteristics information of the color image on image pixel level coarse positioning edge location accuracy is lower ultimately affect the positioning accuracy of subpixel. while the proposed algorithm is on the basis of maximize the image feature information convert projection image and then for subsequent calculations. So the accuracy of the proposed algorithm is superior to the traditional detection algorithm.

(a)The Original Image | (b) The Edge Image of Traditional Algorithms | (c) The Edge Image of the Proposed Algorithms

Figure 4. Edge Detection Results of the Tea Service

In order to further verify the superiority and repeatability of this algorithm we choose another more complex fruit image to do experiment. Figure 5(a)~(c) three images are respectively original image sub-pixel edge image obtained by traditional method sub-pixel edge image got by the proposed method It is obvious that the proposed algorithm can generate clearer and more accurate sub-pixel edge compared with the traditional method.

(a)The Original Image | (b) The Edge Image of Traditional Algorithms | (c) The Edge Image of the Proposed Algorithms

Figure 5. Edge Detection Results of the Fruit Image

4. Conclusion

This paper presents a sub-pixel edge detection algorithm of color images combined gray processing algorithm based on color spatial distance and the least square method the algorithm uses Ostu method to calculate maximum variance between class and minimum interclass variance of target and background so that it can directly obtain the optimal color threshold finally ideal subpixel pixel was obtained by combining subpixel edge detection method of gray images. Experimental results show that the algorithm can avoid repeat detection process for the threshold we can get the optimal threshold value directly by using the Ostu method reduces the running time.At the same time the method combines the advantages of sub-pixel edge detection of gray images its detection effect is good it is conducive to further image analysis and processing. However how to obtain the sub-pixel edge of color images which contain noise is need to study in the future.

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