Wavelet Multi-scale Edge Detection Using Adaptive Threshold

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Abstract—**This paper, taking advantage of multi-scale character of wavelet transform, performs multi-scale wavelet transform of the given image. A wavelet transformation of a given image produces an image that is proportional to the gradient of the smoothed image, and then edges can be detected by locating the local maxima of the magnitude of the resultant image. The wavelet function used in the method is derived from a smoothing function. The edges at different scales are extracted and filtered by using an adaptive threshold, and are synthesized to obtain the final edge image. The experiment proves that the method preserves abundant details and good noise resistance simultaneously.**

Keywords-wavelet transform; multi-scale edge detection; adaptive threshold

I. INTRODUCTION

Edge detection is a crucial step in edge extraction and object delineation in image processing. An effective edge detector reduces a large amount of data but still keeps most of the important features of the image. As one of the first-use methods, edge detection is widely used in imagery data processing such as remote sensing data processing. For example, for an aerial image, a high quality edge detector not only obtains a good understanding of the image but also provides a simple but significant input for the process of extracting edges of some specific objects.

The gradient method is an early technique to detect edges. Basically, this method uses some specifically designed masks to traverse the image and detects edges by locating the maxima of gradient magnitude of the image. The gradient-based edge detection has been widely applied in practice, and a reasonable edge map is obtained for most images. But the method is sensitive to noises, and the masks with fixed sizes cannot be dilated.

Canny's detector is a commonly used tool in edge detection. The method first blurs the input image and then finds the gradient of the blurred image. Edges can then be detected by tracing the local maxima of the magnitude of the gradient image. Canny's detector is optimal for isolated step edges corrupted by white noises and it uses the Gaussian function to smooth the input images. Nevertheless, they suffer from some practical limitations. Firstly, close edges may affect each other in the process especially when the deviation of the Gaussian function is big, which leads to inaccurate edge locations and some edge losses. Secondly, the hysteresis thresholding proposed by Canny requires not only the trial and error adjustment of two thresholds to produce a satisfactory edge result for each different input image, but also the control of the imaging environment to assure the validity of the pre-adjusted thresholds.

Reference [1] introduces a wavelet transformation method in image processing. A wavelet transformation of a given image produces an image that is proportional to the gradient of the smoothed image, and then edges can be detected by locating the local maxima of the magnitude of the resultant image. As an edge detector, this method is essentially equivalent to Canny's method. The wavelet function used in the method is derived from a smoothing function.

The wavelet transformation based edge detection is extensively studied in [2] and [3]. These papers characterize some edges including the step edges through the evolution of the wavelet transformation of the edges at different scales. Importantly, the interferences of close edges during the wavelet transformations are studied, and it's discovered that when a proper dilation scale of the smoothing function is used, the edges of the main objects in the image can be detected well, while the noises and tiny irrelevant objects can be mostly removed.

The paper performs multi-scale wavelet transform of the given image, whose edges at different scales are extracted and filtered by using an adaptive threshold to preserve both strong and weak edges. The edges are then synthesized to obtain the final edge image.

II. WAVELET MULTI-SCALE EDGE DETECTION

The two dimensional dyadic WT of an image $I(x,y)$ at scale 2^j and in orientation k is defined as:

$$W_{2^j}^k f(x,y) = I * \psi_{2^j}^k(x,y), \quad k = 1,2. \tag{1}$$

The two oriented wavelets $\psi_{2^j}^k$ can be constructed by taking the partial derivates

$$\psi^1(x,y) = \partial\theta(x,y)/\partial x, \quad \psi^2(x,y) = \partial\theta(x,y)/\partial y, \tag{2}$$

where $\theta(x,y)$ is a separable spline scaling function which plays the role of a smoothing filter. It can be shown that the two-dimensional WT gives the gradient of $I(x,y)$ smoothed by $\theta(x,y)$ at dyadic scales

$$\begin{aligned}\nabla_{2^j} I(x,y) &\equiv (W_{2^j}^1 I(x,y), W_{2^j}^2 I(x,y)) \\ &= 1/2^{2j}\nabla I * \theta_{2^j}(x,y).\end{aligned} \tag{3}$$

If we want to locate the positions of rapid variation of an image I, we should consider the local maxima of the gradient magnitude at various scales which is given by

$$\begin{aligned}M_{2^j} I(x,y) &\equiv \left\|\nabla_{2^j} I(x,y)\right\| \\ &= \sqrt{(W_{2^j}^1 I(x,y)^2 + (W_{2^j}^2 I(x,y))^2}.\end{aligned} \tag{4}$$

A point (x,y) is a multi-scale edge point at scale 2^j if the magnitude of the gradient $M_{2^j} I$ attains a local maximum there along the gradient direction $A_{2^j} I$, defined by

$$A_{2^j} I(x,y) \equiv \arctan[W_{2^j}^2 / W_{2^j}^1 I(x,y)]. \tag{5}$$

For each scale, we can collect the edge points together with the corresponding values of the gradient, i.e. the WT values, at that scale.

III. ADAPTIVE THRESHOLD METHOD

The multi-scale edge images obtained from wavelet multi-scale edge detection represent edges with different strength, structure, and size, which are important characters of image. If we choose one threshold for the whole transformed image, the local maxima of magnitude from weak edges will be filtered together with magnitude extrema from intensity irregularities and noises. An adaptive threshold method is proposed, in the hope of being effective on edge detection of images with both strong and weak edges.

The wavelet multi-scale edge detection using adaptive threshold method is performed as described in Fig.1.

First, magnitude images $M_{2^j} f(x,y)$ and argument images $A_{2^j} f(x,y)$ are produced through wavelet transform of $f(x,y)$, the original image. Second, for each scale, local extrema of gradient magnitude are detected along the gradient direction determined by $A_{2^j} f(x,y)$, and now probable edge image $P_{2^j}(x,y)$ is obtained. Then the adaptive threshold is to be determined to preserve weak edges, as well as erase fake edges caused by noises and image intensity irregularities. Probable edge image $P_{2^j}(x,y)$ is scanned with a window ($n \times n$), and the threshold is calculated from the wavelet transform coefficients within the window,

$$T = T_0 + \alpha_0 \times \sum_{i,j} C_{i,j}, \tag{6}$$

where T is the threshold; T_0 is initial value of T; $C_{i,j}$ is the corresponding wavelet transform coefficient; α_0 is a scale coefficient to determine how much T depends on $C_{i,j}$. Worth mentioning, the size of the window is important. If the window is too small, noises and intensity irregularities will affect the threshold more, and false alarm rate increases. While the window is too large, weak edges may be filtered. In this paper, the window size is set to 24×24.

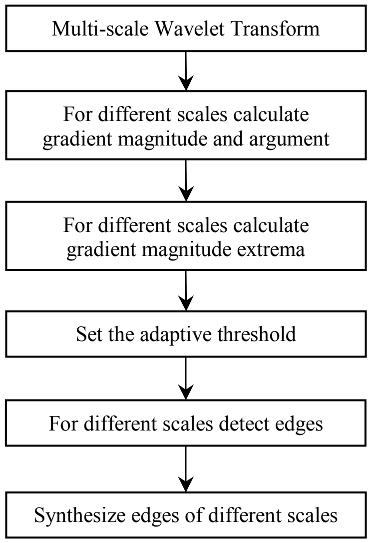


Figure 1. The flowchart of wavelet Multi-Scale Edge Detection

IV. SYNTHESIS OF MULTI-SCALE EDGES

The wavelet transform of an image provides different edge information for each scale level. If the scale is small, edge details are abundant, and the precision of edge location is relatively high, but noises cause disturbances easily. And if the scale is large, the edges are more stable, with good noise resistance but worse precision of edge location. One solution is to synthesize multi-scale edges of the image to obtain a precise edge.

The procedure is as follows:

1) $C^j(x,y)$ denotes the edge image of scale j. As the edge shift between edge images of adjacent scales is within 1 pixel, for each edge pixel in $C^j(x,y)$, search edge pixels in $C^{j-1}(x,y)$ within a 3×3 window centered at the pixel corresponding to the one in $C^j(x,y)$. All found pixels are labeled candidate edge pixels, and all pixels not labeled in $C^{j-1}(x,y)$ are set to zero.

2) Group candidate edge pixels with similar gradient magnitudes and arguments in $C^{j-1}(x,y)$, and link them to form a chain. Delete isolated chains by checking the length of the chains, and the rest chains form an edge image with single pixel width, denoted by $E^{j-1}(x,y)$.

3) Set $j = j-1$. If $j > 1$, go to step 1); if $j = 1$, then edge image $E^1(x,y)$ is the synthesis of multi-scale edges.

V. EXPERIMENT RESULTS AND ANALYSIS

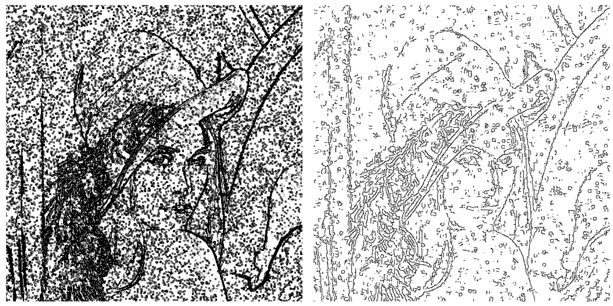
The experiment of wavelet multi-scale edge detection using adaptive threshold shows that the method can detect image edges precisely with good noise resistance. Fig.2 shows the experiment results of our method, Prewitt detector, and Canny detector.

In Fig.2, (a) is the original image of Lenna; (b)(c)(d)(e) are result images for (a); (f) is Lenna with pepper-and-salt noises(noise density is 0.05), and (g)(h)(i) are results for (f).

(a) original lenna (b) Prewitt detector

(c) Canny(0.000004, 0.1) (d) Canny (0.4, 0.4)

(e) our method (f) lenna with noise



(g) Prewitt detector (h) Canny detector

(i) our method

Figure 2. Experiment results

From the experiment results, we can draw the conclusion. The edges obtained by our method are adequate and precisely located, while Prewitt detector can not detect the entire edge. Canny detector can detect adequate edges, but needs adjust two thresholds repeatedly to obtain good edge detection. In addition, our method has better noise resistance.

VI. CONCLUSION

This paper, taking advantage of multi-scale character of wavelet transform, performs multi-scale wavelet transform of the given image. The edges at different scales are extracted and filtered by using an adaptive threshold, and are synthesized to obtain the final edge image. The experiment proves that our method is simple and practical, and preserves abundant details and good noise resistance simultaneously.

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