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Improved Gray-scale Morphological Gradient Edge Detection Algorithm Based on Wavelet Denoising

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Abstract—This paper proposes an edge detection operator based on the combination of soft threshold wavelet denoising and gray morphological gradient for detecting the edge of image with gaussian white noise. When we use traditional detection operators (including Sobel operator, Prewitt operator, Laplacian operator, and Canny operator) to detect the edge of image with gaussian white noise, which will result in lots of noise points being detected and fuzzy edges, it leads to non-ideal result. In this paper, we preprocess image with Gaussian white noise adopting wavelet soft-threshold denoising, then following it we use the algorithm of morphological closing operation and grayscale morphological gradient to detect the edge. The method can effectively remove the noise and give a good detail image edge detection. This algorithm is proposed appropriately for edge detection of image with Gaussian white noise.

Keywords: Morphological edge detection, Gray-scale morphological gradient, Gaussian white noise, wavelet denoising

1. Introduction

That how to use image processing technology to achieve fast and accurate non-contact measurement of object size, is the central issue of the industrial production and engineering application. Image measurement has the features of non-contact, full field, high precision, and its principle is to get the image geometry by processing the image edge of the measured object. Edge is the most basic feature of image. It represents a step change around the pixel gray, so the edge of image contains a wealth of information, while it reflects the basic characteristics of objects.

2. Edge detection based on morphology

Morphology is a theory built on the basis of mathematical disciplines, including Miknowksi structure and difference operation, etc. It can be used to solve image processing problems such as noise suppression, feature extraction and edge detection. The fundamental idea and method have a significant impact on image processing theory and technology. It discards the traditional numerical modeling and analysis point of view, with certain forms of structural elements to measure and extract the corresponding image in the shape to achieve the image analysis and identification purposes. It abandoned the traditional numerical modeling and analysis. In order to achieve the purpose of the analysis and recognition, we use certain forms of structural elements to measure and extract the corresponding shape of image. Mathematical morphology has its unique advantages in image edge detection. It can solve the problem of the coordination of edge detection accuracy and anti-noise performance so that the algorithm is simple but can effectively preserve the details feature of image. The mathematical morphology based on set theory, can be used to simplify image data, to maintain their basic shape characteristics, and to remove extraneous structures. The algorithm has a natural structure with parallel implementation. Mathematical morphology has four fundamental operations: expansion (or extension), corrosion (or erosion), opening and closing. These basic operations can be derived or combined into a variety of practical algorithms of mathematical morphology. At present, traditional morphology has been developed into order morphology and fuzzy mathematical morphology, etc. Each is also equipped with some advantages. For example, order morphology mainly applies local sorting operation which will response to the image shape within the neighborhood around a certain central pixel; fuzzy mathematical morphology is beneficial to detect the edge of a variety of geometric shapes, and in the edge detection algorithm, the opening and closing filtering has implemented impliedly to improve noise immunity.

Four basic operations, that are expansion, corrosion, opening and closing, are as followed:

1. Expansion:

That processing function f from function b with gray-scale expansion is defined as equation (1):

$$(f \oplus b)(s,t) = \max \{ f(s-x,t-y)+b(x,y) \mid (s-x,t-y) \in Df,(x,y) \in Db\} \tag{1}$$

where, Df and Db stand for the field of definitions about function f and b; displacement parameters (s-x) and (t-y) must be included in the field of definition about function f. As expansion choose the maximum value from all f+b in the neighborhood defined by the structural elements, there are two usual results after image processing: first, if all the structural elements are positive, the output image will display more bright than the input image; second, because of increased local brightness, black details will reduce or even remove. The level of reduction or removal depends on the value and shape related to structural elements in the expansion.

2. Corrosion:

That processing function f from function b with gray-scale corrosion is defined as equation (2):

$$(f \ominus b)(s,t) = \min \{ f(s+x,t+y)+b(x,y) \mid (s+x,t+y) \in Df,(x,y) \in Db\} \tag{2}$$

where, Df and Db stand for the field of definitions about function f and b; displacement parameters (s+x) and (t+y) must be included in the field of definition about function f. Similarly, the corrosion of gray image leads to two results: first, if all the structural elements are positive, the output image will display more dimmer than the input image; besides, the bright region smaller than the structural elements will be weakened by corrosion. The level of weakness depends on the gray value around bright areas and the shape and amplitude of the structural elements themselves.

3. Opening:

Use the structure element B to take opening operation on set A. It is expressed as $A \circ B$, whose definition is as equation (3):

$$A \circ B = (A \ominus B) \oplus B \tag{3}$$

Therefore, opening operation on A with B is first corrosion on A with B and later expansion on the results with B. That is the opening operation of grayscale image.

4. Closing:

Use the structure element B to take opening operation on set A. It is expressed as $A \bullet B$, whose definition is as equation (4):

$$A \bullet B = (A \oplus B) \ominus B \tag{4}$$

Therefore, closing operation on A with B is first expansion on A with B and later corrosion on the results with B. That is the closing operation of grayscale image.

Morphology used in image detection, can select structural elements of different forms for diverse images or purposes of detection. But that is, at the same time, the drawback of morphological edge detection, which lies in its poor adaptive algorithm. There is a good solution that combines morphological parameters with the adaptive and optimization theory.

In this paper, we adopt gray image morphological gradient for edge detection. When detecting image edge by gradient, we take it into consideration: if there is a certain point with a large gradient value that represent a rapid change in light and dark of image, where it might exist edge. Several gradients have been put forward in morphological processing and the morphological gradient, to be introduced, which is defined as followed:

$$GRAD(f)=(f \oplus g)-(f \ominus g) \tag{5}$$

where, g stands for the flat structural elements centered at the origin (constant structural elements in the field of definition).

The following figure shows process diagram seeking the gradient of the signal f. g stands for the flat structural elements whose value are zero in the field of definitions. From the figure, output signals have higher values at the transitions of input signal.

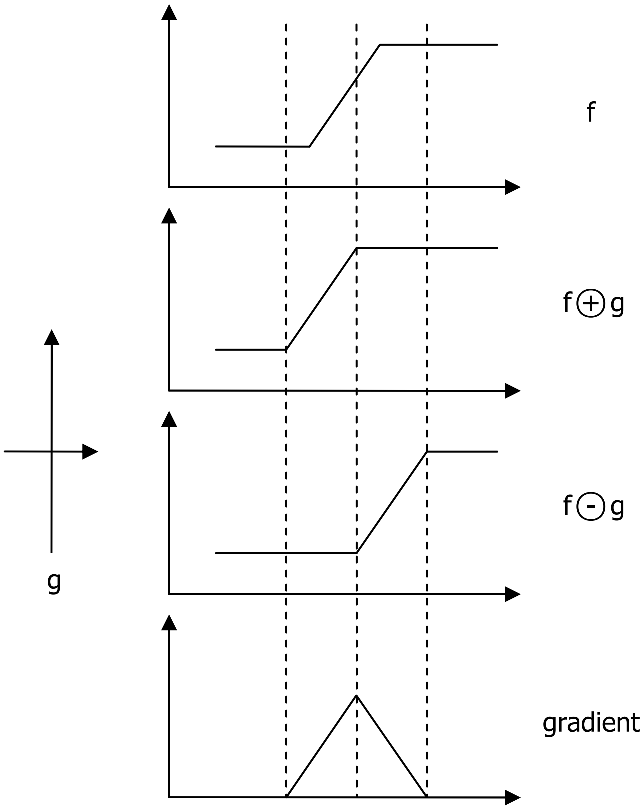

Figure 1. Morphological gradient descriptor

3. Wavelet Denoising

In the process of signal acquisition and transmission, it's inevitable to introduce noise, and it will have a negative impact on the subsequent signal processing. Because of great time-frequency localized properties in the wavelet transformation, we can provide a nice denoising. When taken the mother wavelet function as the first derivative of the smooth function, the modulus of wavelet transformation will get the local maximum at the point mutations. The difference between edge and noise is that, as the scale increases, the maximum modulus of wavelet transformation caused by noise decreases rapidly, but the corresponding modulus of edge will not change, so wavelet leads to the identification of noise and edge at a low SNR.

In the past 20 years, wavelet in image processing has been widely used. As a result of multi-resolution approach, after wavelet transformation, the energy of signal concentrates on the low frequency. At the same time, high-frequency signal describes the non-stationary characteristics well. So wavelet decomposition can accurately capture edge or the singular points of signals.

In mathematics, the nature of the problem of wavelet denoising is a function approximation problem, that is, according to the proposed measurement criterion, how to find the best approximation of the original signal to separate the original signal from noise in the function space stretching from the mother wavelet function and the translation version. From this, it shows that the wavelet denoising method is to get the best mapping from the actual signal space to wavelet function space so as to obtain the best recovery of the original signal.

In signal theory, wavelet denoising is a signal filtering problem. Although wavelet denoising can be seen as a low pass filter to a large extent, it succeeds in preserving image features after denoising, so it is better than traditional low-pass filter. Therefore, the wavelet denoising is actually the integration of feature extraction and low-pass filtering.

The absolute value of wavelet coefficient is a local measure, so each wavelet coefficient is seen as an independent variable. Given a threshold δ, all wavelet coefficients whose absolute values are less than the threshold value of δ are classified as "noise", with zeros instead of their original values; when the wavelet coefficients exceed the threshold, we amend them for new values by deducting threshold value δ from them. This approach means that thresholding or deduction based on wavelet transformation have to do with the removal of minor noise or undesired signal in the wavelet domain. With inverse wavelet transformation we will obtain the required signal. Much to be concerned is that, since boundary conditions are processing by mirror projection, the distortion of edge of image may arise. And with the increasing scale, the distortion of edge is becoming more serious.

Generally, in order to maintain the accuracy of edge, the scales are no more than 4. We decomposed it into 3 scales. Denoising process is mainly the following three steps:

(1) Calculate 3 layers of wavelet transformation of image with noise to get the corresponding wavelet coefficients x;
(2) Respectively calculate the threshold δ for each layer of wavelet coefficients x and process wavelet coefficients by thresholding to get new coefficients y;

$$y = \begin{cases} \operatorname{sgn}(x)(|x| - \delta) & ,|x| \geq \delta \\ 0 & ,|x| < \delta \end{cases} \tag{5}$$

where the δ is the threshold of wavelet coefficients x; f(x) is a linear function. After deducting the wavelet coefficients exceeding the threshold, we can reload their values via f(x).

(3) Inverse wavelet transform, and after the threshold processing, reconstruct the wavelet coefficients to obtain the denoised image.

4. Improved gray-scale morphological gradient

In this paper, we preprocess Lena image with Gaussian white noise adopting wavelet soft-threshold denoising, then following it we use the algorithm of morphological closing operation and grayscale morphological gradient to detect the edge. This method has the characteristics of wavelet multi-resolution, overcoming the contradiction of noise suppression and edge positioning accuracy in the traditional neighborhood selection algorithm, at the same time it has filtering function as a band-pass filter by wavelet transformation. After de-noising in all scales by soft-thresholding method for removing the low amplitude noise or signals that are not expected, both opening and closing operations can eliminate, without global geometric distortion, the specific image details which are smaller than structural elements. Opening operation can directly filter off spike pulse being smaller than structure elements, so it has to do with the separation through cutting the long and thin boundary. On the contrary, closing operator can fill up gap being smaller than structure elements, so it has to do with the connection by lapping short break. Then we filter image noise and edge burr so that we get the edge image. When used gradient edge detection to detect image edge, if there is a certain point with a large gradient value that represent a rapid change in light and dark of image, where it might exist edge. The combination with wavelet denoising and gray-scale morphological gradient is the very core theory of improved algorithm.

Algorithm implementation:

(1) Decompose image matrix to the wavelet coefficients with noise.
(2) Process wave low-frequency coefficients let coefficients such as HL, LH and HH obtained from the decomposition, keep low-frequency coefficients unchanging.
(3) Select the appropriate threshold to remove Gaussian white noise.
(4) In order to get two grayscale images borders, making use of structural elements, we process the low-frequency part with closing and opening morphological operations respectively and produce low-frequency difference.
(5) Process image matrix with inverse wavelet transformation to obtain the denoised image matrix.
(6) In Figure 1, according to gray morphological gradient model, detect image matrix with the morphological gradient to find the gradient extremum.
(7) Refine boundary. In fact, the process of refinement is to use structural elements to remove the pixels whose gradient are not maximum. Finally we get the image edge detected.

5. Experimental results and analysis

This paper takes Lena image with Gaussian white noise as the original one, the first step is to use traditional edge detection operators (including Sobel operator, Prewitt operator, Laplacian operator, and Canny operator) to detect the edge of noise image. By experimental contrast, we can see that the traditional detection operators lead to non-ideal result when used to detect the edge of Lena image with Gaussian white noise. This paper proposed edge detection operator based on combination of soft threshold wavelet denoising and the gray-scale morphological gradient, and when detecting image signals with Gaussian white noise, it can effectively remove the noise and give a good detail image edge detection.

As illustrated in figure 2,3,4,5,6 , Lena image with Gaussian white noise is considered as the original one, then detect the image by traditional detection operators.

Figure 2. Original Lena image with Gaussian white noise

Figure 3. Processing Lena image with Sobel operator

Figure 4. Processing Lena image with Prewitt operator

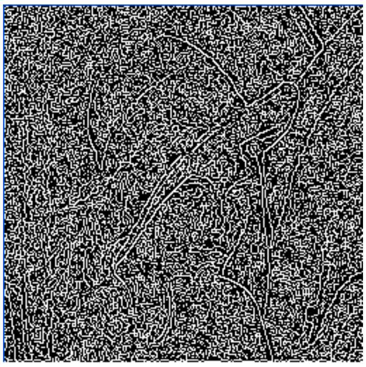

Figure 5. Processing Lena image with Canny operator

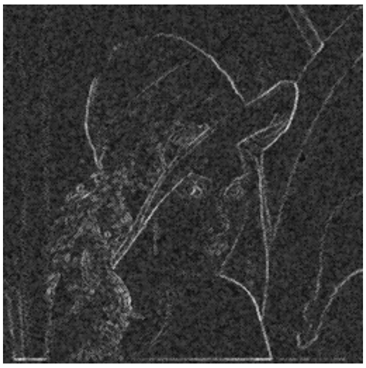

Figure 6. Processing Lena image with Gray-scale morphological gradient approach

From the figure above, after adding Gaussian white noise into image, when we take edge detection with the traditional detection operator, we will detect not only the edge but also all noise points. The details of the image edge detected become very fuzzy and even adopting the classic Canny operator, detection effect is still unsatisfactory, which is mainly because the traditional edge detection operators depend on the difference of neighboring gray value. The adjacent pixels edge's first derivative extremum varies very much, so they can detect the edge of image. When the image contains a lot of noise signals, since there is Gray-scale difference between white noise and image signal, it is also very easy to detect, which will result in a bad result for the classical operator.

Figure 6 shows the edge of image which is based on the method of Gray-scale morphological gradient. The core theory is that, if the gradient value at a certain point is larger than others, it means a rapid change in light and dark of image, which proves an edge there. Because of the images with a large amount of Gaussian white noise, which pollutes the image screen, the transition of the noise point will change the formation of gray gradient, resulting in poor detected results.

This paper proposed an edge detection algorithm of the combination of the soft threshold wavelet denoising and gray scale morphological gradient. It shows in Figure 7:

Figure 7. Processing Lena image with the combination of the soft threshold wavelet denoising and gray-scale morphological gradient approach

As is shown in Figure 7, this method combines wavelet denoising with Gray-scale morphological gradient. To maximum extent, this method manage to filter Gaussian white noise which is concentrated on high-frequency part of the signal, meanwhile owing to its combination with cross-structed morphology gradient, burr of the edge details can be effectively removed. Compared with the classical operators through the experimental figures, we find that the image noise is filtered much cleaner. Filtering Gaussian white noise with wavelet soft-threshold denoising has a more distinct advantage, and gray-scale morphological gradient distinctively improves edge detection effect. This algorithm is proposed appropriately for edge detection of image with Gaussian white noise.

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