An Image Edge Detection Algorithm using Wavelet Transform and Fuzzy Techniques

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Abstract — In this paper we propose an image edge detection algorithm based on wavelet transform and fuzzy techniques. Sharpness of a reproduced image is one of the important criteria for quality of reproduction. Due to influences from some external factors, images, which are transferred between devices and transformed between colour spaces, are not only changed in their colour and their gradation, but also blurred in their details. But the contours and edge information in image needs usually to be extruded. Therefore, except for the colour correction and gradation adjustment of image, the enhancement of image-sharpness, which is the focus here, is very important in image processing. The empirical study shows that the image edge detection algorithm based on wavelet transform and fuzzy techniques can achieve better performance than the traditional algorithm in image edge detection.

Keywords— Image edge detection; Wavelet transform; Copula theory; Fuzzy algorithm

I. INTRODUCTION

In recent years, the study of wavelet transform urged its usage in image coding. The multi-resolution analysis of wavelet transforms matches with the character of human vision. It can give sub-bands for different levels and different directions of an image. Studying the application of wavelet transform in arbitrarily shaped image coding, 3-D transform coding of video, post-processing of decoded image, can promote the consummation of new image/video coding standard, etc., MPEG-4, JPEG-2000.

The protection and enforcement of intellectual property rights has become an important issue in image/video coding system. Fuzzy method and MARCH model is the process of encoding hidden copyright information in an image by making small modifications to its pixels. It can be used for image authentication and forgery prevention. Studying watermark in wavelet domain of image/video, is helpful to include watermarking system into image/video coding standard based on wavelet transform.

In Zhang’s dissertation, following the development of wavelet theory, especially the second generation wavelet transform (the lifting algorithm), Zhang study the usage of wavelet transform in arbitrarily shaped image coding, 3-D transform coding of video, post-processing of decoded image and watermarking in wavelet domain of image/video. The researcher pointed out that coding of arbitrarily shaped image was one of core technology in MPEG-4 video compression.

They first use low-pass extrapolation to enhance the performance of Katata's approach using classical wavelet transform \cite{1}. In order to make algorithm easier, Zhang studies the application of wavelet lifting scheme in transform coding of arbitrarily shaped image objects and presents three new approaches based on lifting algorithm. One needs extrapolation of the image object. The second is a shape-adopted algorithm by modifying the compute of coefficients near the object edge. The third is a shape-adopted algorithm based on modifying boundary extension method of the lifting scheme. The experiment result shows that the image compression performances of approaches using lifting scheme, especially the third one, are better than Katata's approach using classical 3-D wavelet transform and the approach using SA-DCT.

In Ausin’s research, the motion estimation is combined with 3-D wavelet transform for video coding \cite{2}. In classical 3-D wavelet transform of video, wavelet transform of time domain is applied to pixels in the same spatial coordinate of each frame. But in his paper, wavelet transform is applied to pixels in one motion trajectory which is constructed by motion vectors in order to fully utilize the redundancy in the time domain. Because the length of motion trajectory is arbitrarily, a new wavelet transform method for arbitrary length signals is needed. A length-adopted wavelet transform algorithm based on modifying boundary extension method of the lifting scheme is presented in his paper. The experiment result shows that for video sequence with wide range of movement the compression performance of this approach is better than approach using classical 3-D wavelet transform.
In Zhou’s paper [3], the author use de-noising by integer wavelet thresholding in post-processing of decompressed images. In Donoho’s de-noising algorithm, the high/high portion of wavelet coefficients can be used to estimate noise level and threshold value. If the image signal has abundant high-frequency details in high/high portion of wavelet domain, the estimation of threshold value will be interfered. So we use adaptive transform derived from lifting scheme to make distribution of signal energy more concentrated, so that the threshold value can be estimate more efficiently. We also incorporate adaptively into redundant transforms to improve the de-noising performance. From the experiment results, we can see that the PSNR values of recover images after DCT and wavelet transform coding are increased. This algorithm can efficiently remove blocking effect. The author presents a new strategy to embed watermarks to image/video wavelet transform domain. In many papers in literature, the coefficients in the scale sub-band (low-frequency coefficients) are explicitly excluded from watermark embedding in order to maintain transparency. But the coefficients in scale sub-band are bigger than most coefficients in other sub-band. This means the coefficients in scale sub-band have higher perceptual capacity than coefficients in other sub-band. So in this paper, watermarks are embedded into the scale sub-band of image/video wavelet transform domain. The experiment result shows that this watermarking scheme is robust enough and maintains the character of transparency. They also use adaptive wavelet transform derived from lifting scheme to get bigger scale sub-band coefficients [4-5]. The result shows the image watermarking algorithm using nonlinear wavelet transform is more robust than algorithms using usual wavelet transform [6].

II. THEORY ABOUT WAVELET TRANSFORM AND PREWITT OPERATOR

The traditional edge detection method is rely on edge detection operator to detect, such as Roberts operator, Sobel operator, Prewitt operator, LOG operator, Canny operator, which has the advantages of simple operation and strong real-time, but these operators have disadvantage of pseudo edge, while wavelet transform [7] can well remove the noise and can effectively reflect the image grey level change. In order to effectively to image edge detection, operator of the improvements and a variety of detection algorithm fusion has become a hot spot of image edge detection. This paper proposes a kind of edge image fusion detection Method based on improved Prewitt operator edge detection and wavelet transform edge detection. The fusion algorithm combines the advantages of the two methods, and achieved better fusion effect.

The traditional Prewitt operator only has two detection templates of horizontal and vertical direction, edge detection accuracy is not high. In order to improve the edge detecting precision and computing speed, the traditional Prewitt operator is improved in this paper, the edge detecting operator is increased from two to four. But Prewitt operators are sensitive to noise, pseudo edge prone to detection, and the detecting method based on wavelet transform edge not only has good anti-noise, but also can preserve the edge details, this paper puts forward a kind of edge detecting algorithm based on wavelet transform and improved Prewitt operator edge image fusion: first the source image is processed by using median filter method, then the filtered image is enhanced by histogram equalization method, the enhanced image is respectively detected by wavelet transform edge detection method and improved Prewitt operator edge detection method, finally the two edge detecting image is done image fusion by using wavelet image fusion algorithm based on adaptive wavelet image fusion algorithm, Experiments show that the fused image combines the advantages of two kinds of detection algorithm, the fusion detection method can suppress noise effectively, but also can improve the accuracy of edge detection. It is an ideal method of image edge detection.

Prewitt edge detection operator is an edge template operator, which uses grey level difference of upper and lower, left and right neighbouring points to detect edges. The principle of the traditional Prewitt edge detection is in the image space using the template in two directions and image neighbourhood convolution, the two direction templates respectively detects horizontal edges and vertical edges. This operator is usually expressed by the following formula:

\[ G(x) = f(x+1,y-1) - f(x-1,y-1) \]
\[ + f(x+1,y) - f(x-1,y) \] (1)
\[ G(y) = f(x-1,y+1) - f(x-1,y-1) \]
\[ + f(x,y+1) - f(x,y-1) \] (2)

\[ P(x,y) = \max[ G(x), G(y) ] \] or
\[ P(x,y) = G(x) + G(y) \] (3)

The Prewitt Operator template as follows:

\[ G_x = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \] (4)
\[ G_y = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \] (5)

So, from the equations above, we can get:

\[ \mathbf{X} = \mathbf{U} \ast \sum \ast \mathbf{U}^T \] (6)
\[ \mathbf{X}' = \sum \ast -1 \ast \mathbf{U}^T \ast \mathbf{X} \] (7)

Evaluation index of dimensionless uses gravy system theory of effect measure.

For the indicator which became better and bigger:
z(i, j) = S_{\text{max}} + \frac{e(i, j) - \min_j e(i, j)}{\max_j e(i, j) - \min_j e(i, j)} \times (S_{\text{max}} - S_{\text{min}}) \quad (8)

For the indicator which became better and smaller:

z(i, j) = S_{\text{max}} - \frac{e(i, j) - \min_j e(i, j)}{\max_j e(i, j) - \min_j e(i, j)} \times (S_{\text{max}} - S_{\text{min}}) \quad (9)

For e-plus in some appropriate value indicators:

z(i, j) = S_{\text{max}} - \frac{e(i, j) - e_0}{e(i, j) - e_0 + e_0} \times (S_{\text{max}} - S_{\text{min}}) \quad (10)

In the evaluation of the ICP, it can be estimated the edge nodes for selecting is that:

\[ (cm(k, j))_{m \times n} = \sum_{j=1}^{n} \frac{w_j}{k_{x \times y}} \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{w_i}{k_{x \times y}} \quad (11) \]

\[ pc(k, j) = \left\{ e_0, (a_k \triangleright a_j) \right\} \cup (a_k \triangleleft a_j) \quad (12) \]

Prewitt Operator think [8]: all that new pixel grey value greater than or equal to the threshold are edge points, because a lot of noise grey value is large, so the noise caused by misjudgement for edge point, but also for the smaller amplitude of edge point, its edges have lost.

In order to effectively to image edge detection, operator of the improvements and a variety of detection algorithm fusion has become a hot spot of image edge detection. Correlation has been called a mine field for the unwary because it is a technique that is widely misused in finance and is applied to problems for which it is not suitable. A distribution function is a function that assigns probabilities as a function of outcomes that is for every outcome, the distribution function gives the probability.

III. EDGE DETECTION ALGORITHM BASED ON VJAVELET TRANSFORMATION AND MARCH MODEL

Suppose \( \theta(x, y) \) is a two-dimensional smoothing function, and meet

\[ \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \theta(x, y) dx dy = 1 \]

\[ \lim_{s \to \infty} \theta(s, x, y) = 0 \quad (15) \]

If we order:

\[ \theta(x, y) = \frac{1}{S^2} \Gamma \frac{x}{S} \frac{y}{S} \quad (16) \]

Two dimensional signal \( f(x, y) \) smoothing is accomplished at different scales of s and \( \theta(s, x, y) \) do convolution operation to achieve, the first order derivative type along X and Y direction of two as the two basic wavelets is shown as follows:

\[ \frac{\partial \theta(x, y)}{\partial x} = \frac{1}{s^2} \phi \left( \frac{x}{s}, \frac{y}{s} \right) \frac{1}{s^2} \phi \left( \frac{x}{s}, \frac{y}{s} \right) \quad (17) \]

Suppose \( f(x, y) \in L^2(R^2) \), Two dimensional wavelet transform in the scale of s includes two parts:

\[ WT_1 f(x, y) = f(x, y) \ast \phi_1(x, y) \quad (19) \]

\[ WT_2 f(x, y) = f(x, y) \ast \phi_2(x, y) \quad (20) \]

Type as a vector in the form of

\[ \begin{bmatrix} WT_1 f(x, y) \\ WT_2 f(x, y) \end{bmatrix} = \begin{bmatrix} WT_1 f(x, y) \\ WT_2 f(x, y) \end{bmatrix} \quad (21) \]

Be known as f (x, y) Binary wavelet, The \( WT_1 f(x, y), WT_2 f(x, y) \), model of local maximum points corresponding to smooth image in the corresponding
position of the prominent point. Its size reflects the position of the grey intensity. Therefore, the image edge points can be obtained as long as we detect wavelet transform modulus local maxima along the gradient direction.

The MARCH model can be formulated as follows:

\[ r_i = \mu_i(\theta) + \varepsilon_i \quad (22) \]

\[ \varepsilon_i = H_{1/2}G(\theta)Z_i \quad (23) \]

\[ Z_i | F_{i-1} \sim C(u_{i1}, u_{i2}, ..., u_{iN}; \alpha_1, \alpha_2, ..., \alpha_N) \quad (24) \]

\[ E(Z_i | F_{i-1}) = 0 \quad (25) \]

\[ E(Z_i | F_{i-1}) = \sum_{i} = (\sigma_{ij}), \alpha_{ij} = 1 \quad (26) \]

\[ D(x, y, \sigma) \]

is given by,

\[ D(x, y, \sigma) = L(x, y, k\sigma) - L(x, y, \sigma) \quad (27) \]

With the Gaussian blur \( G(x, y, \sigma) \), we have:

\[ L(x, y, k\sigma) = G(x, y, k\sigma) * I(x, y) \quad (28) \]

The direction of the coefficient is calculated using the following formula:

\[ D(X) = D + \frac{\partial D}{\partial X} X + \frac{1}{2} X T \frac{\partial^2 D}{\partial X^2} X \quad (29) \]

\[ m(x, y) = \sqrt{\frac{L(x + 1, y) - L(x - 1, y)^2}{L(x, y + 1) - L(x, y - 1)}} \quad (30) \]

\[ \theta(x, y) = \tan^{-1} \frac{L(x, y + 1) - L(x, y - 1)}{L(x + 1, y) - L(x - 1, y)} \quad (31) \]

The function \( f(x, y) \) with of size \( I_i \) and \( I_2 \) can be shown as

\[ W_\varphi(i_1, i_2) = \frac{1}{\sqrt{I_1 I_2}} \sum_{j_0 \ldots j_{l-1}} f(x, y) \varphi_{i_1, i_2} (x, y) \quad (32) \]

\[ W_\psi(j_1, j_2) = \frac{1}{\sqrt{I_1 I_2}} \sum_{j_0 \ldots j_{l-1}} f(x, y) \psi_{j_1, j_2} (x, y) \quad (33) \]

where

\[ A^{(n)} = \left[ a_{1}^{(n)}, a_{2}^{(n)}, ..., a_{j}^{(n)} \right] \in I_{j_1 \ldots j_{l-1}} \quad (n = 1, 2, 3) \]

represent common factors.

\[ Y = \sum_{j_0 = 1} \sum_{j_1 = 1} \sum_{j_{l-1} = 1} g_{j_1, j_2} a_{j_1}^{(1)} a_{j_2}^{(2)} a_{j_3}^{(3)} + E \quad (34) \]

\[ Y = G \times \{ A \} + E = \hat{Y} + E \]

that is:

\[ D_F(Y \parallel G, \{ A \}) = \frac{1}{2} \| Y - \hat{Y} \|^2 \quad (35) \]

IV. EDGE DETECTION METHODS BASED ON FUZZY ALGORITHM AND WAVELET TRANSFORM IMAGE FUSION

Pre-processing of image edge detection includes image filtering and image enhancement, edge detection algorithm is one order and two order derivative calculation based on image intensity, but the calculation of derivatives is very sensitive to noise, easily affected by noise, therefore, we must use the filter to reduce the noise, but in fact filter to reduce noise at the same time also led to the edge loss of strength. There are many methods of image smoothing filter, such as the mean filter, median filtering and so on, the image can reduce the noise by using the mean filter, but the filtered image edge become blurry and the median filter to filter the image can reduce the noise (especially the salt and pepper noise), and can make the image edge is clear, especially for the salt and pepper noise, filtering effect is good, so here the median filter to pre-process the image edge detection.

Image enhancement is to neighbourhood (or local) intensity values have highlighted some significant changes, Histogram equalization through some grey transform of the original image, so that the transformed image histogram can be evenly distributed, so as to be able to have similar grey area grey and possession of a large number of pixels in the original image to broaden, the tiny grey transform a large area of the display, the image is more clear, in order to grey difference expand the target and background and enhance the intensity contrast between them, in order to more easily detect the image edge details, the image histogram equalization enhancement method to pre-process the image edge detection.

In the process of the image capture and image transmission, noise will be produced unavoidably. The existence of image noise severely affects the effect of subsequent image processing. To enhance the image quality, image de-noising becomes a very important work of image pre-processing. Now, as a new time-frequency analysis method, wavelet transform (WT) has important significance in the actual application. Combined with WT and fractional theory, fractional wavelet transform (FWT) extends multi-resolution analysis to the time domain-general frequency domain. Image enhancement methods can be divided into two roughly: The method of image enhancement in spatial domain and the method of image enhancement in transform domain. The first method literally means enhance the image in the spatial domain, in other words, it means process each pixel in the image directly. In this paper, we use the fuzzy algorithm similar to spatial processing method and some improvements based on the traditional fuzzy algorithm. The second one means transform the original image to a specific domain and enhance the image by modifying the correlation coefficient in transform domain. There are some methods transforming the Images from spatial domain to transform domain, such as Fourier transform, wavelet transform, Contourlet transform, NSCT transform, Shearlet transform and so on.

In order to effectively to image edge detection, operator of the improvements and a variety of detection algorithm
fusion has become a hot spot of image edge detection. This paper proposes a kind of edge image fusion detection method based on the improved Prewitt operator edge detection and wavelet transform edge detection. If the image signal has abundant high-frequency details in high/high portion of wavelet domain, the estimation of threshold value will be interfered. So we use adaptive transform derived from lifting scheme to make distribution of signal energy more concentrative, so that the threshold value can be estimate more efficiently. We also incorporate adaptively into redundant transforms to improve the de-noising performance. From the experiment results, we can see that the PSNR values of recover images after DCT and wavelet transform coding are increased.

V. EXPERIMENT RESULTS

Fig. 1 is the experiment of Lena image with Salt and pepper noise, Fig. 1(a) is the original Lena image, Fig. 1(b) is on the original image onto the salt and pepper noise, Fig. 1(c) is the Lena image after median filtering, filter will filter out salt and pepper noise in large, but also retains many important details of the image, the image is relatively clear, but in the de-noising process will inevitably lose some detail edge. Fig. 1(d) is the image histogram equalization after median filtering, the purpose is to expand the grey difference of target and background and enhance the intensity contrast between them, in order to more easily detect the image edge details. After image histogram equalization, image was enhanced, and the details of the image more clear. Fig. 1(e) is a fuzzy algorithm edge detection based on image enhancement, from Fig. 1(e) can be seen in Lena image edge details, many are not detected, lost a lot of edge detection details, the improved fuzzy algorithm edge detection result is much better than Fig. 1(e), the edge is clearly, as shown in Fig. 1(f), but still lost some grey value changes slowly edge detail, Fig. 1(g) is the image by means of image edge detection algorithm based on wavelet transformation, as can be seen from the image, edge contains the image detail information richer and more continuous, but the edge is rough. image edge detect method Based on improved Prewitt operator and wavelet transform edge image fusion edge is combined with the advantages of the two algorithms, which preserve the edge details, and remove the noise, no pseudo edge appears, as shown in Fig. 1(h) shows, it obtains the satisfactory effect of edge detection. Table 1 shows the comparison results of GA algorithm and image edge detection algorithm based on wavelet transform and fuzzy algorithm
TABLE I THE COMPARISON OF GA ALGORITHM AND IMAGE EDGE DETECTION ALGORITHM BASED ON WAVELET TRANSFORM AND FUZZY TECHNIQUES

<table>
<thead>
<tr>
<th>The number of experiment nodes</th>
<th>Time for wavelet transform and fuzzy algorithm</th>
<th>Probability of finding optimal solution for wavelet transform and fuzzy algorithm</th>
<th>Average value for wavelet transform and fuzzy algorithm</th>
<th>Time for GA</th>
<th>Probability of finding optimal solution for GA</th>
<th>Average value for GA</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>&lt;1s</td>
<td>25%</td>
<td>56.89</td>
<td>≈ 2s</td>
<td>35%</td>
<td>53.63</td>
</tr>
<tr>
<td>500</td>
<td>≈ 1s</td>
<td>58%</td>
<td>52.05</td>
<td>≈ 5s</td>
<td>46%</td>
<td>51.56</td>
</tr>
<tr>
<td>1000</td>
<td>≈ 2s</td>
<td>88%</td>
<td>48.89</td>
<td>≈ 8s</td>
<td>55%</td>
<td>50.06</td>
</tr>
</tbody>
</table>

VI. CONCLUSIONS

This paper presents a fusion method of edge detection of improved fuzzy algorithm and wavelet transform image, by analysis of the experimental results, the algorithm can suppress noise effectively, and can improve the accuracy of edge detection, detection effect is obviously superior to the single image edge detection.

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