# ADAPTIVE FILTER IN LOW QUALITY FINGERPRINT IMAGES*

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**Abstract** A method of fingerprint image enhancement based on BEG algorithm and wavelet transformation was introduced to enhance the image quality. First, a method to estimate the local image gradient, called the BEG (best estimation of gradient) algorithm was proposed to extract the texture orientation parameters. Then the frequency parameters in local fingerprint window were calculated. At last an adaptive Morlet wavelet filter was used to enhance the fingerprint image according to the parameters in the fore steps. The performance test shows that this method is valuable in practical uses.

**Key words** gradient field, frequency field, wavelet transform, BEG algorithm.

# 低质量指纹图像的自适应滤波*

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摘要 提出了基于 BEG 算法和小波变换的方法用以增强图像的质量. 首先提出了局部图像的梯度估计方法, 称之为 BEG(梯度的最佳估计)算法, 用来提取图像的纹理方向特征参数. 然后, 在指纹的局部窗内计算其频率参数. 最后, 根据这些参数, 用 Morlet 小波滤波器对指纹图像进行自适应滤波. 性能测试结果表明, 该算法在实际中具有较高的应用价值.

关键词 梯度场, 频率场, 小波变换, BEG 算法.

## Introduction

Automatic fingerprint recognition system has wide use such as crime identification and access control, etc. In this type of system, the preprocessing of fingerprint image is very important, because it affects the system performance directly.

During the acquisition of fingerprint images, the fingerprints are often in poor quality because of many reasons, bringing many difficulties to the following fingerprint feature extraction and classification. So, the fingerprints from fingerprint acquisition machine cannot be used readily to the recognition and they must be preprocessed. Figure 1 is an example showing a fingerprint image in low quality. The minutiae cannot be marked directly in it.

Fig. 1 Fingerprint image in low quality
图 1 低质量的指纹图像

In this paper, we introduce a method that uses Morlet wavelet filter. An algorithm is proposed, which we call it BEG, to have a best estimation of

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gradients of the sub-windows in fingerprint image. Then the frequency features are represented in the local windows. Next an adaptive wavelet filter is used according to the local features. The experiments show that the algorithm has got good results.

## 1 Gradient Field of Fingerprint Image

Gradient field represents the changes of pixels gray in fingerprint image. A gradient direction in local window can be defined as the main gradient direction of the window. Many methods have been introduced to calculate the local window 's gradient in the references. Dividing the upper half plane into four parts[3], the pixels have the smallest gray square error in the orientation that is perpendicular to the main gradient direction. But the last result is only for gradient directions, it can 't be the precise estimation of the main gradient direction. In Ref. [2] the author first established a goal function about local gradient orientation, then calculated the best estimation of local gradient direction. The gradient module at each pixel weights the goal function defined in the reference. But it doesn 't work when the fingerprint image has much noise, especially when the image is in a sparse state. The last synthesized gradient intensity is very small because they cancel out each other. At this time, it is difficult to determine the main orientation. The following is to describe our method of estimating the main gradient orientation. It is a best estimation, so called the BEG (best estimation of gradient) algorithm.

### 1.1 BEG Algorithm

Given a fingerprint image $I$, the angle of gradient vector at each pixel is defined as $\theta_{i,j}$, the gradient vector as $\vec{d}_{i,j}$ $(i=1,\cdots,M, j=1,\cdots,N)$, $M, N$ as the width and height of the image $I$, respectively, the main orientation vector as $\vec{d}$, orientation angle as $\theta$. Project the unit gradient vector, $\vec{d}_{i,j}$ at each pixel in the local window onto the main orientation vector $\vec{d}$ and sum them:

$$S = \sum_{i=1}^{M}\sum_{j=1}^{N} \| W_{d_{i,j}} \cos(\theta - \theta_{i,j}) \| , \qquad (1)$$

where $W_{d_{i,j}}$ weights the projection from vector $d_{i,j}$ to the main orientation vector.

When $\theta$ varies, it is obvious that the value of $S$ in Eq. (1) also varies. When $S$ arrives the extreme point, $\theta$ is the best estimation of main gradient orientation in local window.

In order to simplify the calculation, rewrite the equation (1) as

$$S = \sum_{i=1}^{M}\sum_{j=1}^{N} W_{d_{i,j}}^2 \cos^2(\theta_{i,j} - \theta). \qquad (2)$$

Differentiating Eq. (2) with respect to $\theta$,

$$\frac{dS}{d\theta} = \sum_{i=1}^{M}\sum_{j=1}^{N} W_{d_{i,j}}^2 \sin 2(\theta_{i,j} - \theta), \qquad (3)$$

Set Eq. (3) to zero, an extreme value of $S$ is obtained. Thus, $\theta$ corresponding to the extreme value $S$ can be solved from the above equation. Value of $\theta$ is as Eq. (4):

$$\theta = \frac{1}{2}\arctan^{-1}\left(\frac{\sum_{i=1}^{M}\sum_{j=1}^{N} W_{d_{i,j}}^2 \sin(2\theta_{i,j})}{\sum_{i=1}^{M}\sum_{j=1}^{N} W_{d_{i,j}}^2 \cos(2\theta_{i,j})}\right) \qquad (4)$$

### 1.2 Algorithm Design

Assume the source image to be $I$, $G$ is its gradient map.

(1) Divide the image $I$ into sub-blocks which have 16×16 pixels in size;

(2) Calculate the gradient $G_x(i,j)$ and gradient $G_y(i,j)$ at each pixel in the image, where $G_x(i,j)$ and $G_y(i,j)$ are the gradient in horizontal and vertical directions. Calculate the orientation angle $\theta_{i,j}$ and gradient intensity $G(i,j)$ through $G_x(i,j)$ and $G_y(i,j)$.

(3) Calculate $W_{d_{i,j}}$: divide the upper half plane into sixteen equal parts, which are used to estimate the gradient orientation in local window. Firstly, map the gradient direction at each pixel into one of the sixteen areas, secondly, make statistics of the numbers $P_i$ $(i=0,...15)$, respectively, which recorded the pixel points located in each of the sixteen areas. Ranking them in the order of decreasing, eight areas from the beginning can be chosen as the main direction areas and set $W_{d_{i,j}}$ as the gradient intensity at the pixel point. In the

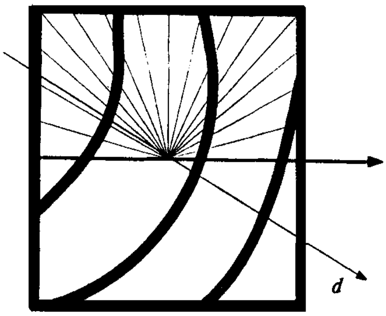


Fig. 2 Sixteen predefined areas for the directions of local fingerprint window
图 2 局部指纹窗中 16 个预定义的方向区域

other eight areas, we set the weight value of $W_{d_{i,j}}$ to zero. The sixteen areas in the upper half plane are shown in Fig. 2.

(4) According to Eq. (4), calculate the gradient field map G. Images shown in Fig. 3 are the gradient maps which are overlapped on the source image. Figure 3(a) is the result gradient map of BEG algorithm, and Fig. 3(b) is the result of the algorithm introduced in Ref [2]. Comparing the two maps, one can infer that our algorithm has stronger ability to resist noise.


(a)

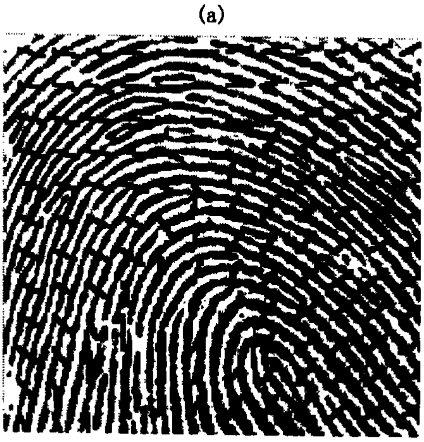
(b)

Fig. 3 Gradient map G of fingerpring
(a) BEG algorithm (b) A. Rao 's algorithm
图 3 指纹图像的梯度图 G
(a) BEG 算法 (b) A. Rao 's 算法

## 2 Frequency Field of Fingerprint Image

In a local window where no minutiae and singular points appear, the pixel gray values can be modeled as a sinusoidal-shaped wave along the direction which is perpendicular to the direction of ridges or valleys. The variations of wave frequency among neighbor windows will be smaller if less minutiae or singular points appear.

Point C, shown in Fig. 4, is the center of sub-window in fingerprint image. $d_1$, $d_2$, $d_3$ are the gradient directions in the sub-window. They go through the quartered points of the dashed line in Fig. 4. Segment out the window from the fingerprint image and draw out the pixel 's gray value curve along the directions $d_1$, $d_2$ and $d_3$. In order to remove the effect of noise, the next step is to average the pixel gray value at directions $d_1$, $d_2$ and $d_3$. The examples of results are shown in Fig. 5.

In order to calculate the spatial frequency of local sub-window, we average the pixel numbers between any two consecutive peaks, marking it using $\overline{T_c}$, then the spatial frequency is $f_c = \frac{1}{\overline{T_c}}$.

When much noise exists in the sub-window, or singular points exist, it 's difficult to obtain an obvious wave peaks and valleys. The frequency of such windows is set to zero. When these frequency values are needed, interpolation can be applied

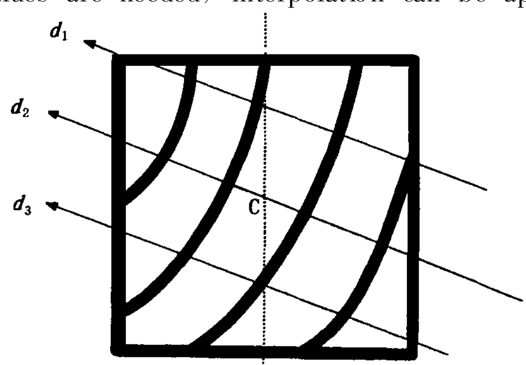


Fig. 4 Calculation of frequency field
图 4 计算频率场

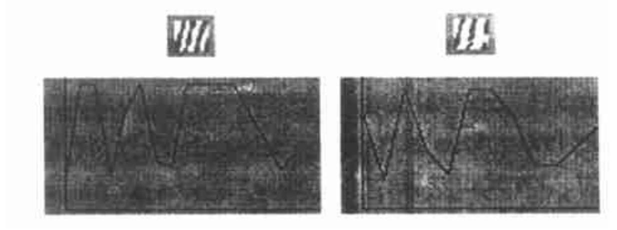

Fig. 5 Gray value curve along the main gradient direction
图 5　主梯度方向上灰度曲线

using the neighboring windows.

## 3 Morlet Wavelet Filter

Wavelet has strong signal-analyzing ability in time-frequency domain. It 's widely used to process the 1-D and 2-D signals.

We define Morlet wavelet as follows:

$$\Psi(x, y, k_x, k_y, \sigma) = \exp\left(-\frac{(k_x x)^2 + (k_y y)^2}{2\sigma^2}\right) \times \exp(i(k_x x + k_y y)), \quad (5)$$

$(x, y)$ are the variables representing the spatial position, $(k_x, k_y)$ are the numbers of waves, $\sigma$ is the standard deviation of Gaussian window. $\tan^{-1}\left(\frac{k_y}{k_x}\right)$ is the orientation angle of wavelet.

The wavelet transformation of image $I$ can be expressed as the convolution of image $I$ and Morlet basis functions, shown in Eq. (6):

$$G(k, x_0, y_0) = \int \Psi_{x_0, y_0}(x, y) I(x, y) \mathrm{d}x \mathrm{d}y. \quad (6)$$

When we design the wavelet filter, we only hold its cosine elements. The parameters can be set as follows:

(1) Set the frequency of wavelet filter to $k_c f_c$ ($f_c$ is the frequency of local window, $k_c$ is a constant);

(2) $\sigma$ is a constant;

(3) Set wavelet angle to the angle of the main gradient vector($\theta$) in local fingerprint window.

## 4 Experiment Result and Performance Test

For a fingerprint image with 512×384 pixels in size, which can be divided into blocks with size of 16×16, calculate the gradient map at each pixel points and have an estimation of main gradient vectors in local windows, using the method introduced in section 2. Then compute the frequency field in each sub-windows using the technique in section 3. After that, having gradient field and frequency field of fingerprint image, we can do the adaptive wavelet filtering to remove the noise in fingerprint image and enhance its quality. The experiment result is shown in Fig. 6.

For the fingerprint image, the gradient of neighboring pixel points varies much in the area full of high noise, and the composite intensity of gradient vectors at each pixel in the local window will be very small because they will cancel out each other. So we can use the composite gradient intensity as a performance of our algorithm. When our

Fig. 6 Source image (a) and the filtered image (b)
图 6　源图像 (a) 和滤波图像 (b)

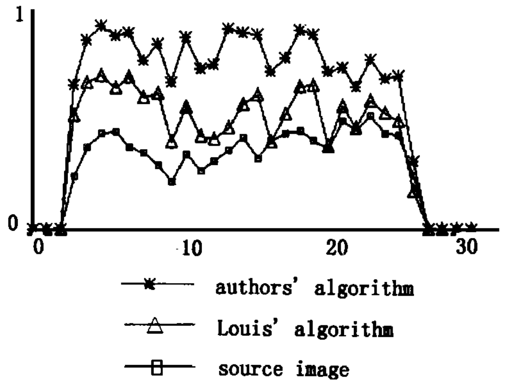


Fig. 7 Curves representing the composite gradient intensity
图7 合成梯度强度曲线

algorithm has better result, the composite intensity will be stronger than others' and the gradient vectors should distribute uniformly in a range. Take out the sub-windows in the middle line of fingerprint image as the sample data and the composite intensity curves can be drawn out. The curves are shown in Fig. 7. The curve with little squares represents the composite gradient intensity of source image, the one marked with triangles represents the composite gradient intensity of image processed using the algorithm in Ref. [3], and the curve with stars represents the intensity of image filtered using our algorithm. One can find that the image quality has been improved more using our algorithm, as compared with the curves in Fig. 7.

## 5 Conclusion

We have proposed the BEG method to optimally estimate the gradient field of fingerprint image, and exploited another feature-frequency field. On this basis, we use the wavelet filter to do the adaptive image filtering, and have a performance test using the composite gradient intensity. Experiment results show that our method has enhanced the fingerprint image quality much.

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