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A NOVEL FINGERPRINT ENHANCEMENT METHOD WITH CURVE ACCUMULATION

HUANG Zhong-Wen QI Fei-Hu CHEN Han-Feng
(Department of Computer Science and Engineering, Shanghai Jiaotong University, Shanghai 200030, China)

Abstract The fingerprint enhancement scheme based on Markov Random Field(MRF), which is applied to capture local statistical regularities of ridges, is presented. Then the curve accumulation guided by ridge direction and magnitude is repeated until statistics difference can be acquired between fingerprint ridges and valleys. Experimental results show that this approach can improve the clarity of ridge and valley structures of fingerprint images and meanwhile preserve the minutiae well.
Key words fingerprint enhancement, minutiae, image filter, Markov modeling, curve accumulation.

一种基于曲线累积的指纹图像增强新方法

黄中文 戚飞虎 陈韩锋
(上海交通大学计算机工程系,上海,200030)

摘要 提出了一种基于马尔可夫随机场的指纹图像增强新方法,它用来描述纹线的局部随机特性,然后多次进行曲纹线方向和幅值引导的曲线累积,直到能够区分指纹中脊与谷的统计差别.实验结果表明这种方法不仅能提高指纹图像中纹线脊与谷的对比度,还能有效保持纹线的细节特征.
关键词 指纹增强,指纹特征,图像滤波器,马尔可夫模型,曲线累积.

INTRODUCTION

Fingerprint has been used by police departments since late 1800s and computerized fingerprint processing has been commonplace since 1960s. Uniqueness of fingerprint is determined by the local ridge characteristics and their relationships. ridge ending and bifurcation(Fig. 1) are widely used as local ridge characteristics. AFIS (Automated Fingerprint Edentification system) depends on these minutiae to identify a person while these minutiae rely heavily on the quality of the fingerprint image. The collected fingerprints may contain noise, ink blotches and smudges. Many enhancement methods have been proposed [1 ~ 6] based on this information.

These approaches can be classified into two groups. One is spatial filtering. Connell J H [1] used a weak model to enhance fingerprint image. Lin H [2] introduced an algorithm, which decomposes the input fingerprint image into a set of filtered images then adaptively strengthen image in the recoverable regions. Jiang X D [3] presented a fingerprint enhancement method with an oriented smoothing filter only at selected pixels where necessary. Saatci E [4] enhanced fingerprint ridges by selecting a directional filter based on CNN Gabor-type filters with parameters match ridge features at each point. The other is Fourier filtering which first transforms the fingerprint into Fourier domain then performs filter. Sherlock B G. [5] enhanced fingerprint images based on non-stationary directional Fourier domain filtering. Toshio K [6] designed two distinct fingerprint filters in the Fourier do-

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Fig. 1　Ridge ending and bifurcation
图 1　纹线端点与分叉

main, a frequency filter and a direction filter. By minimizing the energy function selected with image features, an enhanced image can be generated.

There still exist some problems. All the above methods require a reliable ridge orientation extraction while the direction is not accurate especially in the fingerprint core. Moreover, the edge is liable to be over sharpened and simgular point is extended after the orientation filtering. A significant number of spurious minutiae will be generated.

In this paper, we propose a novel fingerprint enhancement scheme based on a MRF Fig. 2 shows the flowchart of fingerprint enhancement process.

1　Estimation of Local Orientation[7]

Fingerprint orientation plays an important role in the procedure of image enhancement. We calculate the orientation of fingerprint images with the Dominant Ridge Direction (DRD). Main steps of the algorithm are as follows:

1) Compute the gradients $\partial_x(i,j)$ and $\partial_y(i,j)$ at each pixel(i,j), the center of a w * w window (the value of w should be adjusted according to the scan resolution of fingerprint image Normal value of w in our research is 17). The gradient operator can be the 3 * 3 Subel operator.

2) Estimate the local orientation of each pixel

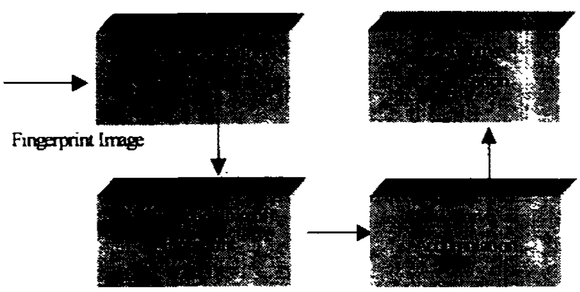

Fig. 2　Flowchart of fingeprint enhancement algorithm
图 2　指纹增强算法的流程图

$$\theta(i,j) = \frac{1}{2} * \arctan\left(\frac{\sum_{u=i-w/2}^{i+w/2}\sum_{v=j-w/2}^{j+w/2} 2\partial_x(u,v)\partial_y(u,v)}{\sum_{u=i-w/2}^{i+w/2}\sum_{v=j-w/2}^{j+w/2}\left[\partial_x(u,v)^2 - \partial_y(u,v)^2\right]}\right). \quad (1)$$

3) Adjust the direction $\theta(i,j)$ with the following rules:
If the denominator is positive then

$\theta(i,j) = \theta(i,j) + \pi/2$,

Elseif the numerator is positive then $\theta(i,j) = \theta(i,j) + \pi$,

Else $\theta(i,j)$ keeps unchanged.

With this algorithm, an orientation field of fingerprint image is obtained. Core and delta area can be detected from the direction of image due to the larger variability in their neighboring block. By adjusting the window size their shape can be kept. When pixel locates near the core or delta area, the size of the window is chosen small. If pixel locates at main ridge area, the size of the window keeps normal.

2　Markov Random Field Model

Statistical features based on second-order gray a concise representation for textures.

Markov random field models have become useful in several fields of image processing. The most important characteristic of MRF is that the information contained in the local structure of image is sufficient to obtain a global representation. Suppose a random field $z = \{z(x), x \in \Lambda\}$, where Λ denotes a finite set of sites of an N * N rectangular lattice. The Markov (locality) property with respect to N states that $p(z) > 0$, for all z and

$$p(z(x_i) \mid z(x_j), \forall x_j \neq x_i) = p(z(x_i) \mid z(x_j), \forall x_j \in \eta_{ij}). \quad (2)$$

Where η_{ij} denotes the ij^{th} pixel's neighborhood.

Due to the equivalence between MRF and Gibbs distributions, established by Hammersley and Clifford, the joint probability density function of any conditional distribution which satisfies the positivity, locality, and homogeneity property can be represented by a Gibbs distribution.

$$p(z) = \frac{1}{Q}\exp(-U(z)). \quad (3)$$

Here z is a realization from the configuration space $\Omega_Z = Q_Z^{N*N}$ with Q_Z denoting the set from which Z_{ij} takes its values, and $U(z)$ is the energy function. Please refer to Ref. [8] for more details on MRF and related definitions.

We regard the neighboring area of a particular fingerprint image pixel is enough to reflect its ridging information, which is the characteristic of MRF. So we use the Gibbs distribution in Eq. 3 to present the probability that a point is selected during the procedure of ridge tracing and curve accumulation.

3 Curve Accumulation

Curve accumulation includes three parts: random ridge tracing, curve accumulation and adaptive binarisation.

3.1 Ridge tracing

Choosing starting point, selecting tracing point and determining ending point are three steps in ridge tracing.

3.1.1 Choosing starting point

Because our method is based on statistical characteristics, the selection of the starting point is not critical while potential starting points selection is important. Experiment shows that the more rigorous the potential starting point set is, the better effect of noise eliminating. A point can be selected as a potential starting point if the gray value is less than a small region's mean.

We use the following PDF with Gibbs distribution to describe the possibility that a starting point is selected.

$$p(v_i) = \begin{cases} m_i \exp(-m_i v_i) & v_i \geq 0 \\ 0. & v_i < 0 \end{cases} \quad (4)$$

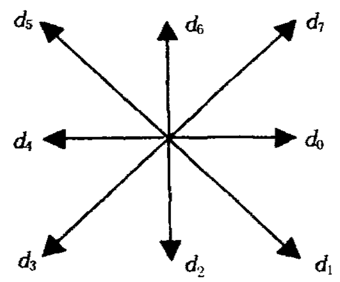

Fig. 3 Ridge direction
图3 纹线方向

m_i is the amplitude of the potential starting points, the expectation of Eq. (4) is $1/m_i$, which means that the larger amplitude is, and the less possibility is selected.

3.1.2 Selection of extension points

Several articles have proposed different methods to select the extension points[9], which are sensitive to noise. We use the local ridge orientation to limit the points set in order to eliminate the effect of noise. Rules are as follows.

a) Extension point set of a starting point is limited by the direction of the ridge. We use d_k, $k = 0, 1 \cdots 7$ to present the neighboring points (Fig. 3).

If the ridge direction at the i^{th} pixel is j($j \in 0, 1 \cdots 3$ which presents for 0, $\pi/4$, $\pi/2$, $3\pi/4$ respectively), the extension points set are $\{d_{j\bmod 8}, d_{(j-1+8)\bmod 8}, d_{(j+1)\bmod 8}\}$ and $\{d_{(j+3)\bmod 8}, d_{(j+4)\bmod 8}, d_{(j+5)\bmod 8}\}$, which means that it has two possible choice and can lead two different direction tracing. The probability of choosing the points is determined by Eq. (4).

b) Non-starting points extension is not only limited by the local ridge direction, but also limited by the last tracing direction because there is no abrupt direction change in the local curve[9], which means that if the last tracing direction at i^{th} pixel is j, then the next possible extension point set is $\{d_{j\bmod 8}, d_{(j-1+8)\bmod 8}, d_{(j+1)\bmod 8}\}$. In addition, ridge tracing is also limited by the local ridge direction, that is, if the local direction is k, the extension set is $\{d_{k\bmod 8}, d_{(k-1+8)\bmod 8}, d_{(k+1)\bmod 8}, d_{(k+3)\bmod 8}, d_{(k+4)\bmod 8}, d_{(k+5)\bmod 8}\}$. The possible extension point set is the intersection of these two sets.

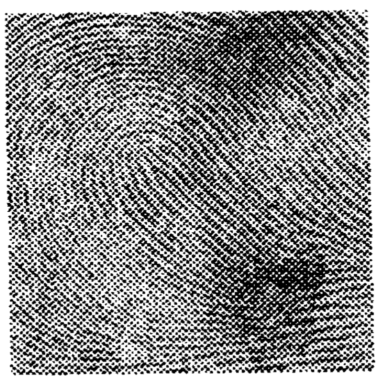

Fig. 4 Original fingerprint image
图4 原始指纹图像

If the next pixel is out of window (window size is 64) or the magnitude is lower than ε, whose value is determined by the fingerprint image that cuts the pixel numbers to 1: 2 in window, it is regarded as an ending point and ridge tracing is stopped.

3.2 Curve accumulation

Compared with traditional tracing algorithm, where the bending level of the ridge and high bending level or large contrast variation of the ridge will result in a short tracing line, our ridge tracing algorithm is processed randomly and can trace a long length of ridge.

One ridge tracing is not enough because the selection of the next point is determined stochastically. Only a large quantity of ridge tracing can reflect the statistic representation. So the repeat number of ridge tracing N is important. Theoretically, the larger N is, the better result will be obtained. N equals to the number of potential initial starting point in our experiment.

Suppose there is a tracing ridge $T=\{(i,j)_0,(i,j)_1,\cdots,(i,j)_{Q-1}\}$ and accumulator at point (x,y) in processing window is represented as $A(x,y)$ with initial value of zero, then the accumulator is updated as following.

$$A(x,y) = \begin{cases} A(x,y) & (x,y) \notin T \\ A(x,y) + \Delta A. & (x,y) \in T \end{cases} \tag{5}$$

ΔA is simply assigned 1 in our experiment but can be a mean value of the tracing ridge. After N times ridge tracing, the curve accumulation is finished.

3.3 Adaptive binarisation

We can view a clear ridge area as the foreground and the other area as background in fingerprint image.

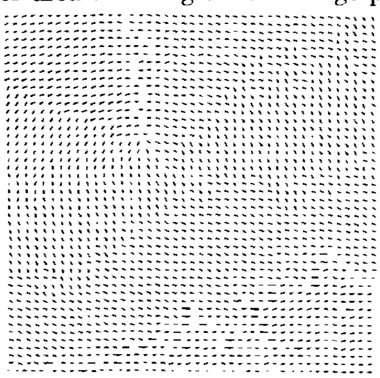

Fig. 5 Orientation field with DRD
图 5　用 DRD 方法获得的指纹方向图

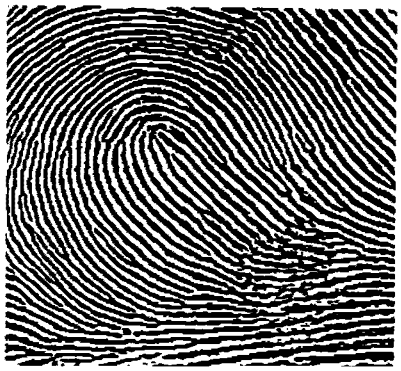

Fig. 6　Results of binarisation with normal direction filering
图 6　一般定向滤波后的二值化图

Binarisation is such a kind of procedure that separates the clear fingerprint area from the background area. The general segmentation is based on the assumption that noise regions have no dominant direction while clear regions flow in a particular direction in a given region. In detail, variance in the direction of ridge is low while it is high in the direction of orthogonal to the local orientation.

Because the histograms of fingerprint images are not bimodal, it is impossible to choose a proper threshold from the histogram. After comparison with direction binarisation and mean binarisation, we found that adaptive average threshold is the most suitable. Average value is computer in a window based on the curve accumulation and then it is multiplied with a coeffcient and regarded as a threshold. The coefficient can be 1/3, 1/2, or 1, depending on the portion of traced and accumulated points to the whole window area, which is an indication of noise region.

Fig. 7　Results of binarisation with curve accumulation guided by magnitude only
图 7　仅由幅值引导曲线积累的二值化图

Fig. 8 Results of binarisation with curve accumulation guided by ridge direction and magnitude
图 8 由幅值与纹线方向引导曲线累积的二值化图

4 Experiment Results

Fingerprints are inked and impressed on paper in our experiment. Then prints on the paper are digitized into gray images of size 512 by 512. Fig. 4 illustrates the raw fingerprint image. Fig. 5 shows the local orientation field of the raw image with DRD, it can be observed that most of the direction of the ridges is correctly extracted although some area of the fingerprint image is smudged or over inked. Fig. 6 is the results of the ordinary directional filtering where many false minutiae were created although the ridge contrast is strengthened. It is due to the arbitrary enhancement along the ridge direction. Fig. 7 shows the results of curve accumulation guided by magnitude and presents that the mutual influence between adjacent ridges in the process of curve accumulation can not be get rid of if the ridge direction is not taken into account. Fig. 8 shows the results of adaptive binarisation (window size is 5) after curve accumulation guided by magnitude and local ridge direction. Ridge tracting is conducted in two directions simultaneously in our experiment with the advantage of better effects.

5 Conclusion

In the paper we present a MRF and curve accumulation based fingerprint enhancement approach, which uses the MRF model to capture local statistical regularities of ridges and curve accumulation to enhance the fingerprint image. Our method is easier for implementation and can not only efficiently improve the clarity of ridge and valley structures of input fingerprint but also preserve the minutiae well.

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