Improved Pattern-based Fingerprint Image Preprocessing and Binarization Algorithm

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***Abstract*—In this paper, by using the improved fingerprint pattern, the fingerprint preprocessing effect of using Gabor filtering have been effectively improved. Then, by combining the advantages of the direction-based binarization algorithm and the local threshold algorithm, this paper can effectively get the fingerprint image binarization and remains the topological structures of the image. Finally, the experiments prove that the fingerprint image enhancement and improved binarization algorithm can improve the accuracy of the fingerprint feature extraction.**

Keywords-Image enhancement, Binarization, Recursive algorithm

I. INTRODUCTION

Generally speaking, fingerprint identification mainly contains fingerprint image acquisition, preprocessing, binarization, thinning, feature extraction and matching. The preprocessing is the key to the fingerprint automatic recognition algorithm. But, the common algorithms for it have the following problems:

1. Due to can not take full inherent characteristics of the fingerprint (e.g. orientation, frequency, consistency and so on), these algorithms cannot restore the structure which were drowned out by noise or dry and make a poor effect in processing too dry and too wet image.

2. The binarization algorithms, such as the direction-based binarization [1], the local thresholds and other algorithms [2], all have advantages and disadvantages and still have areas to improve.

Taking into account that the fingerprint image has strong characteristics in texture and direction, this paper presents the image enhancement preprocessing algorithm and the binarization algorithm to solve the above issues.

II. THE IMPROVEMENT OF PATTERN CALCULATION AND THE OPTIMIZATION OF BINARIZATION

In current, the preprocessing algorithm for fingerprint image is quite mature, and the most popularity one is the Gabor filter segmentation algorithm based on direction [3-5]. Gabor filter has the characteristic that can connect the time domain and frequency domain in the best resolution, so can make a good balance between them. But for poor quality fingerprint images (such as too dry and too wet), this method cannot get a good effective. However, if we enhance the image before the preprocessing of Gabor filtering, the effect for poor quality fingerprint image will significantly improves.

A. The improvement of direction calculation of fingerprint

Because the typical fingerprint image is the texture image, so its ridge line can be calculated with the image gradient information in block. Pattern which can be directly obtained from original gray image is very important to preprocessing and feature extraction. The pattern describes the tangential direction of the ridge or valley line of each pixel in the image. Because the direction of each pixel of fingerprint image in an appropriate region is almost the same, so the direction of the block is often used to instead of the direction of the pixel in actual calculation. The direction calculation of fingerprints directly affects the preprocessing effect of the Gabor filtering. Existing algorithms [4][6], have a common characteristic, that is, in large block, the calculated results are crude but relatively reliable; in a small block, the calculated results are accurate but the anti-noise ability is poor. This paper improves the algorithm by calculating the ridge line direction in different block sizes. First calculates in large block, and then calculates the square gradient consistency of the point in this block area to determine whether to continue to split it into smaller blocks. If the square gradient consistency of the small block is still not satisfied, this small block would be considered as a background or noise in this fingerprint image. This algorithm not only integrates the reliability and accuracy, but also not increases the complexity of the algorithm.

Let $G(i, j)$ is the gray value of the fingerprint image G at the point of (i, j). The calculation steps are as follows:

(1) Divide the fingerprint image which has been preprocessed into non-overlapping blocks with the size of M×M.

(2) For each pixel $f(i, j)$, using the following two templates, respectively, to calculate the x, y direction gradient $G_x(i, j)$ and $G_y(i, j)$.

TABLE I. TEMPLATE 1

1	**2**	**1**
0	0	0
-1	-2	-1

TABLE II. TEMPLATE 2

-1	**0**	**1**
-2	0	2
-1	0	1

(3) For each block which its center is (i, j), its direction calculation formula is as following:

$$\theta = \frac{1}{2}\arctan\left\{\frac{\sum_{i=0}^{M-1}\sum_{j=0}^{M-1} 2G_x(i,j)G_y(i,j)}{\sum_{i=0}^{M-1}\sum_{j=0}^{M-1}[G_x^2(i,j)-G_y^2(i,j)]}\right\}. \quad (1)$$

$$G_x \neq 0, G_y \neq 0$$

(4) Calculates the square gradient consistency $coh(i, j)$ for each point in the block. Its calculation formula is as following:

$$coh(i,j) = \frac{\sqrt{\left[\sum_{i=-w/2}^{w/2}\sum_{j=-w/2}^{w/2}(G_x(i,j)^2-G_y(i,j)^2)\right]^2+\left[\sum_{i=-w/2}^{w/2}\sum_{j=-w/2}^{w/2}2G_x(i,j)G_y(i,j)\right]^2}}{\sum_{i=-w/2}^{w/2}\sum_{j=-w/2}^{w/2}(G_x(i,j)^2+G_y(i,j)^2)}. \quad (2)$$

If the square gradient vector of all points within one block have the same direction, the value of coh close to 1. If the square gradient vector of all points within one block uniformly point to all directions, then coh tends to 0. Therefore, the coh reflects the divergence degree of the block's direction, and its value is between 0 and 1.

Here, setting the experience threshold T_{coh}. If $coh < T_{coh}$, then set $N = M / 2$, and calculates $coh(i, j)$ using formula (2.1) and (2.2). If still $coh < T_{coh}$, then judge this block to be a background or noise region, and mark it as $mask(i, j)$. Among them, $mask(i, j)$ =1 indicates that the point corresponding to the fingerprint region; $mask(i, j)$ =0 indicates that the point corresponding to the background or noise region.

(5) Assuming the ridge line direction of all pixels within each block to be the same, the pattern which is corresponding to the original image can be got. Then, do low-pass filtering in the regions which their $mask(i, j) = 1$.

In the fingerprint image, except the center point and the triangle point, the direction of fingerprint ridge line is generally continuous changing. Therefore, the low-pass filter can be used to smooth the mutation of the ridge line direction and can correct the calculation error caused by noise. In this way, the direction of the ridge line can more accurately reflect the trend of the ridge line. The algorithm of fingerprint ridge direction is as follows:

Divide the image into blocks with the size of W*W.

Set the value of W to be 8, 16 and 32, and calculate the directions of these blocks.

Correct the directions of the blocks when their sizes are 16*16.

Use same way to correct the directions of the blocks when their sizes are 8*8.

Use the Gaussian low-pass filter to smooth the image direction.

Experimental results show that the improved pattern increase the preprocessing effect of the Gabor filter segmentation algorithm. In the areas of direction rapidly changing, this improvement has played a role in denoising and smoothing, and ensures the accuracy of the logical topology which is extracting from feature point. OPTIMIZATION

B. The optio pattern-based fingerprint image binarization algorithm

The crux of binarization lies in the selection of threshold value. In current, the commonly used binarization method mainly contains fixed threshold method, adaptive threshold method, context filters method [2] [9], parallel pixel-based method [8] and so on. But these methods only use the gray information of the image, so binarization of this fingerprint image is not ideal. Another binarization algorithm is the direction-based gray value second derivative zero-crossing method binarization [3]. This method makes full use of the texture characteristics of the fingerprint. The fingerprint image, as a typical texture image, has following characteristics: along the perpendicular direction of ridge (from the ridge to the valley), the gray value first increase, and then decrease and become a ridge. Therefore, the value of the second derivative of the gray changing is zero at the junction of ridge and valley line, is less than zero at the valley line, and is greater than zero at the ridge line. The reference [7] uses the sign of the second derivative to determine the boundary between valley and ridge, and then get the binarization of the image. The main advantage of this method is not need to determine the threshold by person, and can produce the continuous binary image in the low contrast area. However, in the area of the fingerprint which the direction is rapidly changing, this method may cause to the binarization cannot accurate reflect the logical topology of the texture of the original image. This is not allowed in a highly accurate AFIS.

This paper combines the block average iteration and the reference [7] and presents an improvement algorithm. This algorithm partially eliminates the defect that the binarization cannot accurate reflect the logical topology of the texture in the area which direction is rapidly changing. The improved binarization algorithm idea is that: determine whether direction of the fingerprint texture occur mutation in the area of block; If so, then use the block average iteration method to replace the second derivative zero-crossing method to obtain the binary image.

Specific algorithm is as follows:

Here, let the image width is $Width$, height is $Height$, the value of direction changing is thd, the threshold of the direction changing is T, the memory space of the texture pattern is $DirectGraph$, the mask memory space of the texture pattern is $GraphMask$, the size of direction block is $BlockSize$ and its value is 8;

(1) Use the block average iteration method to do image binarization

(2) $Height \times (width - l/2)$ Use the second derivative zero-crossing method to do image binarization. Among them, l is the width of the window.

(3) Detect and track the locations which have the direction mutation. And then, record the number of block which have the direction mutations.

(4) Use the local threshold method to recalculate to the recorded block.

(5) Since the second derivative zero-crossing method uses the direction information around point (i, j) within a range of $w \times l$, so merges the most right $w \times l / 2$ boundary and the left part.

(6) If the image still has small holes, using the block average iteration method to remove them.

Among them, $T = \pi * 10 / 9$.

The block average iteration method: First, calculates the maximum and minimum gray value of each pixel in each block. Here, the maximum gray value is denoted by $iMaxGrayValue$, and the minimum gray value is denoted by $iMinGrayValue$. Then, calculates the average of them, and denotes it by $iNewThreshold$. If the gray of the pixel is less than the average, calculates its gray average value $iMean1GrayValue$; if the gray of the pixel is greater than the average, calculates its gray average value $iMean2GrayValue$. Finally, let $iNewThreshold$ is equal to the average value of $iMean1GrayValue$ and $iMean2GrayValue$, and estimates the gap between $iNewThreshold$ and $iThreshold$. If the gap is zero, let the value as the final threshold; otherwise, iterates 100 times to get the final threshold.

The second derivative zero-crossing method [7]: Let the grey value of pixels (i, j) is $I(i, j)$, and let the ridge line direction of pixels (i, j) is $\theta(i, j) \in [0, \pi)$. So, the second derivative along the $v = [-\sin\theta(i, j), \cos\theta(i, j)]^T$ direction of the gray value (the curved surface is expressed by pixels gray value) is $I''(i,j) = I^{(2,0)} \sin^2\theta(i,j) + I^{(0,2)}(i,j)\cos^2\theta(i,j) - I^{(1,1)} \sin 2\theta(i,j)$.

Among them, $I^{(p,q)}(i, j)$ is the $(p+q)$-th partial derivatives of the gray value surface at the point of (i, j), p is along the horizontal axis, q is along the vertical axis. The continuous surface $z = f(x, y)$ can be obtained by fitting the pixel gray values in the window $(2L+1)(2L+1)$ having (i, j) as a center. The partial derivative of the pixels (i, j) is approximately expressed by the corresponding partial derivative of z. Specific formula is as follows:

$$I^{(p,q)}(i,j) \approx \frac{\partial^{p+q} f(x,y)}{\partial x^p \partial y^p}. \quad (3)$$

$$f(x,y) = \sum_{m=0}^{T} \sum_{n=0}^{T} g_{m,n} h_m(x) h_n(y). \quad (4)$$

$$I^{(p,q)}(i,j) \approx \sum_{c=-L}^{L} f_{p,L}(c) \left(\sum_{r=-L}^{L} I(i-c, j-r) f_{q,L}(r) \right) \quad (5)$$

Among them, $f_{p,L}$ and $f_{p,L}(r)$ is the stimulated response of the bounded one-dimensional pulse filter with the length $2L+1$, the coefficients is given by the following formula:

$$f_{0,L}(l) = \frac{3\left(3L^2+3L-l-5l^2\right)}{(2L+1)(2L-1)(2L+3)}. \quad (6)$$

$$f_{1,L}(l) = \frac{-5l\left(15L^4+30L^3-15L+5-21L^2l^2-21Ll^2+7l^2\right)}{L(L+1)(2L+1)(L-1)(2L-1)(L+2)(2L+3)}. \quad (7)$$

$$f_{2,L}(l) = \frac{30\left(3l^2-L^2-L\right)}{L(L+1)(2L+1)(2L-1)(2L+3)}. \quad (8)$$

$l \in [-L, L]$

Control the length parameter L of the filter is the key. If the value of L is too small, it will lead the continuous surface z too greater adapt to the observation data, and thus cannot distinguish and remove noise; If L is too large, z may be too simple and cannot close to the fingerprint ridge lines in the window. This paper let L is the 0.5 times of the ridge line spacing. The calculation method of ridge line spacing can read in reference [4] and [7].

III. EXPERIMENTS

Processing 200 pieces of fingerprint images uses the both before and improved algorithm.The statistics show that the improved algorithm has a better effect than the old algorithms with the probability of 95% in the circumstances that the direction is violent changing or the image is too dry or too wet. Therefore, this method is effective. Fig. 1 shows some typical experimental results.

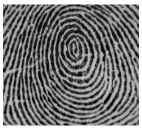

Figure 1. Original fingerprint image

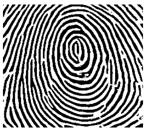

Figure 2. Original binarization image

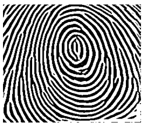

Figure 3. Improvement binarization image

IV. CONCLUSION

This paper presents a fingerprint image preprocessing method based on improved pattern and a improved fingerprint image binarization method. By using the improved algorithm of fingerprint pattern, the fingerprint image preprocessing effect of the Gabor filtering has been enhanced. By combining the advantages of the direction-based binarization algorithm and the local threshold algorithm, this paper presents an effectively fingerprint image binarization algorithm. It not only can maintain the topological structures of the image, but also solves the problem of too dry for image. Experiments show that the fingerprint image enhancement and improved binarization algorithm improve the accuracy of the fingerprint feature extraction, enhances the weak information in too dry and too wet fingerprint image, and restores some missing information.

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