A New Ridge Orientation based Method of Computation for Feature Extraction from Fingerprint Images

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Abstract—An important step in studying the statistics of fingerprint minutia features is to reliably extract minutia features from the fingerprint images. A new reliable method of computation for minutiae feature extraction from fingerprint images is presented. A fingerprint image is treated as a textured image. An orientation flow field of the ridges is computed for the fingerprint image. To accurately locate ridges, a new ridge orientation based computation method is proposed. After ridge segmentation a new method of computation is proposed for smoothing the ridges. The ridge skeleton image is obtained and then smoothed using morphological operators to detect the features. A post processing stage eliminates a large number of false features from the detected set of minutiae features. The detected features are observed to be reliable and accurate.

Keywords—Minutia, orientation field, ridge segmentation, textured image.

I. INTRODUCTION

FINGERPRINTS can be represented by a large number of features, including the overall ridge flow pattern, ridge frequency, location and position of singular points (core(s) and delta(s)), type, direction, and location of minutia points, ridge counts between pairs of minutiae, and location of pores[2].All these features contribute to fingerprint individuality. In this study, we have chosen minutia representation of the fingerprints because it is utilized by forensic experts, it has been demonstrated to be relatively stable and it has been adopted by most of the commercially available automatic fingerprint matching systems. For automatic feature extraction and matching the set of fingerprint features is restricted to two types of minutiae ridge endings and ridge bifurcations as shown in Fig. 1.

Fig. 1 Two types of minutiae (a) Ridge Ending and (b) Ridge Bifurcations

II. PROBLEM DEFINITION

One of the main problems in extracting structural features is due to the presence of noise in the fingerprint image. Commonly used methods for taking fingerprint impressions involve applying a uniform layer of ink on the finger and rolling the finger on paper [1]. These cause the following types of problems (i) Over inked areas of the finger create smudgy areas in the image (ii) Breaks in ridges are created by under inked areas and (iii) The skin being elastic in nature can change the positional characteristics of the fingerprint features depending upon the pressure being applied on the fingers. Although inkless methods for taking fingerprint impressions are now available, these methods still suffer from the positional shifting caused by the skin elasticity. The non cooperative attitude of suspects or criminals also leads to smearing in parts of the fingerprint impressions. Thus a substantial amount of research reported in the literature on fingerprint identification is devoted to image enhancement techniques. This work proposes a reliable method for feature extraction from fingerprint images. The matching stage uses the position and orientation of minutia features. As a result, the reliability of feature extraction is crucial in the performance of fingerprint matching.

III. PROPOSED SOLUTION

The salient features of the proposed approach for feature extraction can be described as follows. A fingerprint image should be viewed as a flow pattern with a definite texture. An orientation field for the flow texture is computed [3]. The input image is divided into equal sized blocks. Each block is processed independently. The gray level projection along a line perpendicular to the local orientation field provides the maximum variance. Locate the ridges using the peaks and the variance in this projection. The ridges are thinned and the resulting skeleton image is enhanced using an adaptive morphological filter. The feature extraction stage applies a set

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of masks to the thinned and enhanced ridge image. The post processing stage deletes noisy feature points. The overall process can be divided into following operations

A. Noise removal
B. Foreground segmentation
C. Normalization
D. Calculation of dominant directions
E. Quantization of the dominant directions
F. Ridge segmentation
G. Ridge smoothing
H. Thinning and smoothing
İ. Extracting minutiae points
J. Minutiae post processing

A. Noise Removal

The 'salt and pepper' noise present in a fingerprint image can be removed using median filter. The median filter is preserves useful details in an image. With median filtering, the value of an output pixel is determined by the median of the neighborhood pixels, rather than the mean. The median is much less sensitive than the mean to extreme values (called outliers). Median filtering is therefore better able to remove these outliers without reducing the sharpness of the image [4].

B. Foreground Segmentation

The foreground regions correspond to the clear fingerprint area containing the ridges and valleys, which is the area of interest. The background corresponds to the regions outside the borders of the fingerprint area, which do not contain any valid fingerprint information. When minutiae extraction algorithms are applied to the background regions of an image, it results in the extraction of noisy and false minutiae. Thus, segmentation is employed to discard these background regions, which facilitates the reliable extraction of minutiae. In a fingerprint image, the background regions generally exhibit a very low grey-scale variance value, whereas the foreground regions have a very high variance. Hence, a method based on variance threshold [5] can be used to perform the segmentation. Initially, the image is divided into blocks and the grey-scale variance is calculated for each block in the image. If the variance is less than the global threshold, then the block is assigned to be a background region; otherwise, it is assigned to be part of the foreground. The result is as shown in Fig.2. The grey-level variance for a block of size N × N is defined as:

$$VAR(I) = \frac{1}{N^2} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \left(I(i,j) - M(I) \right)^2 \tag{1}$$

where *VAR (I)* is the variance for block *I*, *I(i; j)* is the grey-level value at pixel (i; j), and *M(I)* is the mean grey-level value for the block *I*.

(a)   (b)

Fig. 2 Foreground segmentation (a) Original image (b) Segmented image

C. Normalization

The quality of the ridge structures in a fingerprint image is an important characteristic, as the ridges carry the information of characteristic features required for minutiae extraction. Ideally, in a well-defined fingerprint image, the ridges and valleys should alternate and flow in locally constant direction. This regularity facilitates the detection of ridges and consequently, allows minutiae to be precisely extracted from the thinned ridges. However, in practice, a fingerprint image may not always be well defined due to elements of noise that corrupt the clarity of the ridge structures. This corruption may occur due to variations in skin and impression conditions such as scars, humidity, dirt, and non-uniform contact with the fingerprint capture device [10]. Thus, image enhancement techniques are often employed to reduce the noise and enhance the definition of ridges against valleys. A gray-level fingerprint image I is defined as a N × N matrix, where $I(i, j)$ represents the intensity of the pixel at the ith row and j[th] column. We assume that all the images are scanned at a resolution of 500 dots per inch (dpi), which the resolution is recommended by FBI(Federal Bureau of Investigation) . The mean and variance of a gray-level fingerprint image I are,

$$M(I) = \frac{1}{N^2} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} I(i,j) \tag{2}$$

and,

$$VAR(I) = \frac{1}{N^2} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \left(I(i,j) - M(I) \right)^2 \tag{3}$$

Normalization is used to standardize the intensity values in an image by adjusting the range of grey-level values so that it lies within a desired range of values. Let $N(i; j)$ represent the normalized grey-level value at pixel (i, j). The normalized image is defined as

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$$N(i,j) = \begin{cases} M_0 + \sqrt{\dfrac{VAR_0 (I(i,j) - M)^2}{VAR}}, & if\, I(i,j) > M \\ M_0 + \sqrt{\dfrac{VAR_0 (I(i,j) - M)^2}{VAR}}, & otherwise \end{cases} \quad (4)$$

where M_0 and VAR_0 are the desired mean and variance respectively. Normalization is pixel-wise operation. It does not change the clarity of the ridge and furrow structures. The main purpose of normalization is to reduce the variation in gray level values along ridges and furrows, which facilitates the subsequent processing steps

D. Calculation of Dominant Directions

The orientation image represents an intrinsic property of the fingerprint images and defines invariant coordinates for ridges and furrows in a local neighborhood as shown in Fig.3. By viewing a fingerprint image as an oriented texture, a number of methods have been proposed to estimate the orientation field of fingerprint images [6]. Given normalized image, N, the main steps for calculating dominant directions are as follows:

a. Divide N into blocks of size w × w (8× 8).

b. Compute the gradients $\partial_x(i,j)$ and $\partial_y(i,j)$ at each pixel. The gradient operators are simple Sobel operators.

c. Estimate the local orientation of each block centered at pixel *(i, j)* using

$$V_x(i,j) = \sum_{u=1}^{w}\sum_{v=1}^{w} 2\partial_x(u,v)\partial_y(u,v), \quad (5)$$

$$V_y(i,j) = \sum_{u=1}^{w}\sum_{v=1}^{w} (\partial_x^2(u,v) - \partial_y^2(u,v)), \quad (6)$$

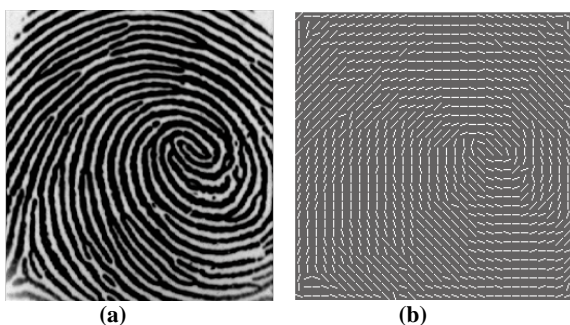$$\theta(i,j) = \frac{1}{2}\tan^{-1}\frac{V_x(i,j)}{V_y(i,j)} \quad (7)$$

E. Quantization of the Dominant Directions

It is difficult to plot all the directions in each block, because of the number of pixels available for plotting directions. All dominant directions should be quantized into eight main directions. All possible directions should get converted into eight directions in the range of 90 degrees to -67.5 degrees. So we consider only 8 main directions. If some direction is in between two major values, it has to be assigned the nearest value.

F. Ridge Segmentation

A new technique has been developed to locate the ridges. A ridge center maps itself as a peak in the projection. The projection waveform facilitates the detection of ridge pixels. A new method has been introduced for finding ridges in the fingerprint image with the help of eight different masks. It is a process of making a binary image of ridges from the grayscale fingerprint image.

The eight masks to be used correspond to the eight quantized directions. This basic idea is that when we move one pixel along the X axis, the number of pixels to be moved along Y axis is *x*.tan (*θ*). The quantized directions are 0, 90, 22.5,-22.5, 45,-45, 67.5,-67.5.

For each block the orthogonal direction of its dominant direction is also calculated

The masks will be placed on each block according to the direction orthogonal to the dominant direction of the block. Here the mask size is equal to the block size. In each mask, the decimal numbers are arranged along a line with an angle equal to the dominant direction of the block on which it is to be placed. The pixels along each line of the mask are examined. The pixel with minimum value is converted to one, while the others are converted to zero. This process is called binarization of the fingerprint image. After the binarization only those pixels correspond to the ridges will remain. The eight different masks of the size 8x8 are as shown in the figures (Fig. 4 to Fig. 11).

Fig. 3 Calculation of dominant directions (a) Original fingerprint image (b) Orientation field of the fingerprint image

Fig. 4 Mask for 90 degrees

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1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8

Fig. 5   Mask for 0 degrees

1	2	3	4	5	6	7	8
2	3	4	5	6	7	8	9
3	4	5	6	7	8	9	10
4	5	6	7	8	9	10	11
5	6	7	8	9	10	11	12
6	7	8	9	10	11	12	13
7	8	9	10	11	12	13	14
8	9	10	11	12	13	14	15

Fig. 6   Mask for 45 degrees

8	7	6	5	4	3	2	1
9	8	7	6	5	4	3	2
10	9	8	7	6	5	4	3
11	10	9	8	7	6	5	4
12	11	10	9	8	7	6	5
13	12	11	10	9	8	7	6
14	13	12	11	10	9	8	7
15	14	13	12	11	10	9	8

Fig. 7   Mask for -45 degrees

1	1	2	2	3	3	4	4
2	2	3	3	4	4	5	5
3	3	4	4	5	5	6	6
4	4	5	5	6	6	7	7
5	5	6	6	7	7	8	8
6	6	7	7	8	8	9	9
7	7	8	8	9	9	10	10
8	8	9	9	10	10	11	11

Fig. 8 Mask for 22.5 degrees

4	4	3	3	2	2	1	1
5	5	4	4	3	3	2	2
6	6	5	5	4	4	3	3
7	7	6	6	5	5	4	4
8	8	7	7	6	6	5	5
9	9	8	8	7	7	6	6
10	10	9	9	8	8	7	7
11	11	10	10	9	9	8	8

Fig. 9 Mask for -22.5 degree

1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8
2	3	4	5	6	7	8	9
2	3	4	5	6	7	8	9
3	4	5	6	7	8	9	10
3	4	5	6	7	8	9	10
4	5	6	7	8	9	10	11
4	5	6	7	8	9	10	11

Fig. 10   Mask for 67 degrees

4	5	6	7	8	9	10	11
4	5	6	7	8	9	10	11
3	4	5	6	7	8	9	10
3	4	5	6	7	8	9	10
2	3	4	5	6	7	8	9
2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8

Fig. 11 Mask for -67 degrees

G. Ridge Smoothing

Once the ridges are located, directional smoothing is applied to smooth the ridges as shown in Fig.12. The same masks used for ridge segmentation can be used for directional smoothing. Here for each and every block, a mask gets selected according to the dominant direction of the block. Each pixel on every line is checked. If the count of `1's is more than 25% of the total number of pixels in the line , then the ridge point is retained by making all the pixel values of the line 1s. If the count of 1's is less than 25% of the total number of pixels in the line, all the pixel values are made 0s.
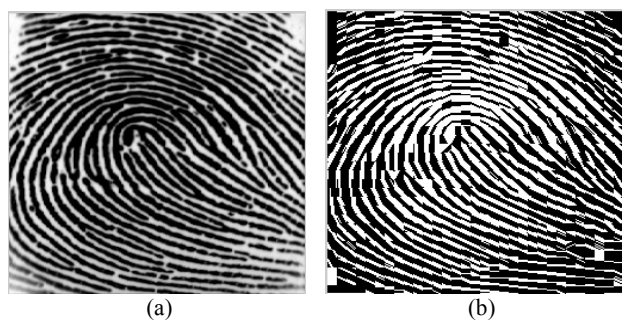

Fig. 12 Ridge smoothing (a) Original Image (b) Image after ridge segmentation and smoothing

H. Thinning and Smoothing

The final image enhancement step typically performed prior to minutiae extraction is thinning. Thinning is a morphological operation that successively erodes away the foreground pixels until they are one pixel wide. A standard thinning algorithm [7] is used, which performs the thinning operation using two sub iterations. The application of the thinning algorithm to a fingerprint image preserves the connectivity of the ridge structures while forming a skeletonized version of the binary image. This skeleton image is then used in the subsequent extraction of minutiae. After thinning there will be some spikes

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present in the binary image. These spikes are removed using directional smoothing.

I. Extracting Minutiae Points

The most commonly employed method of minutiae extraction is the Crossing Number (CN) concept [8]. This method involves the use of the skeleton image where the ridge flow pattern is eight-connected. The minutiae are extracted by scanning the local neighborhood of each ridge pixel in the image using a 3x3 window. The CN value is then computed, which is defined as half the sum of the differences between pairs of adjacent pixels in the eight neighborhoods. Using the properties of the CN, the ridge pixel can then be classified as a ridge ending, bifurcation or non-minutiae point. For example, a ridge pixel with a CN of one corresponds to a ridge ending, and a CN of three corresponds to a bifurcation.

J. Minutiae Post Processing

False minutiae may be introduced into the image due to factors such as noisy images, and image artifacts created by the thinning process. Hence, after the minutiae are extracted, it is necessary to employ a post processing stage in order to validate the minutiae. Some examples of false minutiae include the spur, hole, triangle and spike structures [9]. A method based on certain heuristic rules is used to eliminate minutiae within certain threshold distance from each minutia to minimize the number of false minutiae. Furthermore, a boundary effect treatment is applied where the minutiae below a certain distance from the boundary of the foreground region are deleted. The effect of post processing is shown in Fig.13.
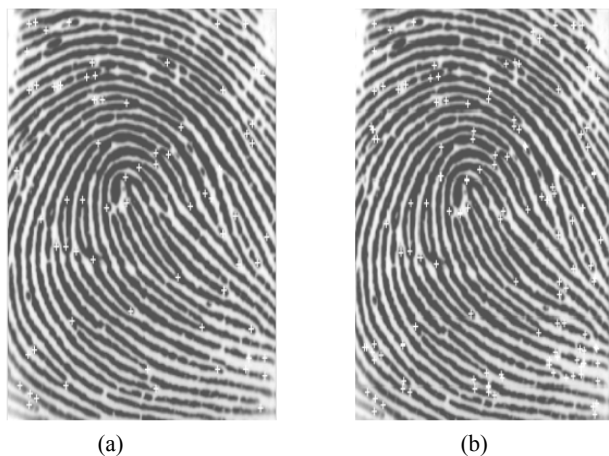

Fig. 13 Extracted minutiae points (a) after post processing (b) before post processing

IV. Algorithmic Parameters

a. Window (block) size: 8x8 pixels, in an input image of size 256×256.
b. Number of quantized directions in orientation field:8.
c. Ridge segmenting and smoothing mask size: 8×8.
d. Threshold on sum of variances in a window to decide background/foreground: 200.

e. Parameters in post processing: Threshold distance of 5 pixels.
f. Different Common minutiae percentages for the matching: 25%, 20% and 15% of the total minutiae present.
g. Different thresholds on translation allowed for the matching: 5, and 6 pixels.

V. Experimental Results

The algorithmic parameters such as the variance of the smoothing windows, and the number of directions in the orientation field were empirically determined by running the algorithm on a set of test images. The feature extraction algorithm described in this paper has been implemented and tested on a database of 350 fingerprints taken from 88 individuals (63-male,25-Female) in the age group of 20 to 30 with Hamster optical fingerprint scanner as the scanning device(25.3(W) x 40.7(L) x 67.7(H) mm,500 dpi). The following results are observed.

The performance of the algorithm has been evaluated in terms of GAR (Genuine Acceptance Rate), FRR (False Rejection Rate) and FAR (False Acceptance Rate) for various common minutiae percentages with a threshold distance of 3 pixels. The corresponding experimental results are shown in Table I. The performance evaluation of the algorithm has been tested again in terms of GAR, FRR and FAR for various threshold distances with common minutiae percentage as 15%.The corresponding results are shown in Table II.

TABLE I
EXPERIMENTAL RESULTS FOR DIFFERENT COMMON MINUTIAE PERCENTAGES

Common Minutiae (%)	Genuine Acceptance Rate (%) GAR	False Rejection Rate (%) FRR	False Acceptance Rate (%) FAR
25	91.66	8.34	0
20	93.18	6.82	0
15	94.12	5.88	0

TABLE II
EXPERIMENTAL RESULTS FOR DIFFERENT PIXEL DISTANCES

Pixel Distance	Genuine Acceptance Rate (%) GAR	False Rejection Rate (%) FRR	False Acceptance Rate (%) FAR
5	95.2	4.8	6.1
6	96.7	3.3	7.6

VI. Conclusion

A new method for robust feature extraction from fingerprint images based on ridge flow orientations has been developed. The main contributions are:

a. A new computation method for ridge segmentation.
b. A new computation method for ridge smoothing.

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The input image quality did not adversely affect the performance of the technique. Ridge segmentation based on peak detection of the projected waveform and morphological filtering results in a good skeleton image.

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REFERENCES

[1] N. Ratha, S. Chen, and A. K. Jain, "Adaptive flow orientation based feature extraction in fingerprint images". Pattern Recognition Vol.28, No. 11, pp. 1657–1672, 1995.

[2] A. K. Jain, L. Hong, S. Pankanti, and R. Bolle, "An Identity Authentication System Using Fingerprints," Proc. IEEE, Vol. 85, No. 9, pp. 1365-1388, 1997.

[3] A Ravishankar Rao, "A Taxonomy for Texture Description and Identification", Springer Verlag, New York 1990.

[4] L. Yin, R. Yang, M. Gabbouj, Y. Neuvo. "Weighted Median Filters: A Tutorial", IEEE Trans. on Circuits and Systems, 43(3), pp. 157-192, March 1996.

[5] B.M. Mehtre, "Fingerprint image analysis for automatic identification", Machine Vision and Applications Vol 6, pp.124-139, 1993.

[6] M. Kawagoe and A. Tojo, "Fingerprint Pattern Classification," *Pattern Recognition*, Vol. 17, No. 3, pp. 295-303, 1984.

[7] Guo, Z., and Hall, R. W. "Parallel thinning with two-sub iteration algorithms". Communications of the ACM Vol.32, No. 3 pp. 359–373, March 1989.

[8] Amengual, J. C., Juan, A., Prez, J. C., Prat, F., Sez, S., and Vilar, J. M. "Real-time minutiae extraction in fingerprint images". In Proc. of the 6th Int. Conf. on Image Processing and its Applications, pp. 871–875, July 1997.

[9] Q. Xiao and H. Raafat. "Fingerprint image post processing   A combined statistical and structural approach", Pattern Recognition Vol. 24, No.10: pp. 985-992, 1991.

[10] L. Hong and A. K. Jain, "Classification of Fingerprint Images," 11th Scandinavian Conference on Image Analysis, June 7-11, Kangerlussuaq, Greenland, 1999.

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