Fingerprint Minutiae Extraction

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Abstract— The most widely used method for fingerprint recognition is based on minutiae matching. A critical step in such systems is to automatically and reliably extract minutiae from the input fingerprint images. However, fingerprint images are rarely of perfect quality. They may be degraded and corrupted due to variations in skin and impression conditions. Thus, image enhancement techniques are employed prior to minutiae extraction to obtain more reliable estimation of minutiae locations. The objective of this paper is to present a fingerprint minutiae extraction method. It includes two main steps: fingerprint image enhancements and minutiae extraction. Two methods are adopted for Image Enhancement: the first one is based on Fourier Transform and the other is Histogram Equalization. Minutiae extraction process includes Binarization, Thinning, Minutiae Detection, and finally removing false minutiae. The validity of adopted algorithms is tested on fingerprint images of FVC2002 database. A good ratio of true minutiae detection is achieved.

Index Terms— minutiae, image segmentation, enhancement, binarization, thinning.

1 INTRODUCTION

Fingerprint is a unique feature to an individual. It stays with the person throughout his life. This makes the fingerprint a very reliable kind of personal identification because it cannot be forgotten, misplaced, or stolen. Fingerprint authorization is potentially the most affordable, easy and convenient method of verifying a person's identity.

A fingerprint pattern is composed of a sequence of ridges and valleys. The ridges are the raised skin; while the valleys are the lowered skin [1], [2]. In fingerprint image, the ridges appear as dark lines while the valleys are the light areas between the ridges (Fig. 1).

Fingerprints are fully formed at about seven months of fetus development and finger ridge configurations do not change throughout the life of an individual except due to accidents such as bruises and cuts on the fingertips [3].

Fingerprint patterns structures can be discussed from global and local levels.

Fig. 1 Fingerprint Pattern

- At the global level, the global ridge structure and singularities or singular regions are concerned.
- At the local level, structures, called minutiae, refers to various ways that the ridges can be discontinuous. For example, a ridge can suddenly come to an end (termination), or can divide into two ridges (bifurcation). It is these features that Automatic Fingerprint Identification Systems (AFISs) extract and compare for determining a match. They are consisted of (Fig. 2) [3]:

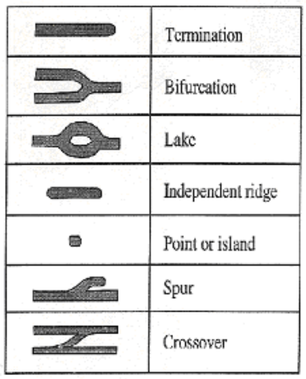

Fig. 2 minutiae types

- **Ridge ending (Termination)-** a ridge that ends abruptly;
- **Bifurcation -** a single ridge that divides into two ridges;
- **Enclosure or lake** - a single ridge that bifurcates and reunites shortly afterwards to continue as a single ridge;
- **Short ridge (independent ridge)** - a ridge that commences, travels a short distance and then ends;
- **Dot (point or island)** - an independent ridge with approximately equal length and width;

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- **Spur** - a bifurcation with a short ridge branching off a longer ridge; and
- **Crossover or bridge** - a short ridge that runs between two parallel ridges.

Fingerprint matching techniques can be placed into two categories: minutiae-based and correlation-based. Minutiae-based techniques first find minutiae points and then map their relative placement on the finger. Correlation-based technique looks into the overall pattern of ridges and valleys. Instead of looking for tiny minutia points, the locations of whorls, loops and arches and the directions that they flow in are extracted and stored.

Most automatic systems for fingerprint comparison are based on minutiae matching; hence reliable minutiae extraction is an extremely important tasks and a lot of research has been devoted to this topic [3]. The quality of input fingerprint images plays an important role in the performance of the minutiae extraction algorithms. So, it is necessary to employ image enhancement techniques prior to minutiae extraction to obtain a more reliable estimate of minutiae locations.

In this paper we propose a fingerprint minutiae extraction method that detects minutiae and can be used in fingerprint recognition system. We will follow the identification model used by the Federal National Bureau of Investigation [3]. This model is based on two minutiae classification: termination and bifurcation. Our method involves two basic stages:

- Pre-processing: which include image segmentation and enhancement.
- Minutiae extraction: which include binarization, thinning, minutiae detection and removing false minutiae.

The rest of the paper is organized as follows. Section 2 elaborates related works. Sections 3 and 4 present proposed preprocessing and minutiae detection stages with experimental results. Final results are demonstrated Section 5.

2 RELATED WORKS

2.1 Image Enhancement

The performance of a fingerprint minutiae extraction and matching algorithm depends critically upon the quality of the input fingerprint image. The "quality" of a fingerprint roughly corresponds to the clarity of the ridge structure in the fingerprint image.

Due to the non-stationary nature of the fingerprint image, general-purpose image processing algorithms are not very useful in this regard but serve only as a preprocessing step in the overall enhancement scheme [3]. Pixel oriented enhancement schemes like histogram equalization [4], mean and variance normalization , Wiener filtering improve the legibility of the fingerprint but do not alter the ridge structure [5].

The most widely used technique for fingerprint image enhancement is based on the use of contextual filters. In conventional image filtering, only a single filter is used that operates on the entire image. In contextual filtering, the filter parameters change according to the local ridge frequency and orientation.

O'Gorman et al. proposed the use of contextual filters for fingerprint image enhancement for the first time [6]. They defined a mother filter whose major axis is oriented parallel to the ridges. The local ridge frequency is assumed constant, so the context is defined only by the local ridge orientation. They recomputed the filter in 16 directions. The image enhancement is performed by convolving each point of the image with the filter in the set whose orientation is best matches the local ridge orientation.

Hong, Wan, and Jane [7] proposed a method based on Gabor filters. The even symmetric form of the Gabor elementary function is given by

$$g(x,y) = \exp \left\{ -\frac{1}{2}\left[\frac{x^2}{\sigma_x^{\,2}} + \frac{y^2}{\sigma_y^{\,2}}\right]\right\}.\cos(2\pi f x). \quad (1)$$

Where f represents the ridge frequency. The filter for any other direction may be obtained by rotating the elementary kernel. the choice of σx and σy determines the shape of the filter envelope and also the trade of between enhancement and spurious ridges and valleys.

Sherlock and Monro [8] perform contextual filtering completely in the Fourier domain. The filter used is separable in radial and angular domain and is given by

$$H(\rho,\theta) = H_{radial}(\rho).\ H_{angle}(\theta), \quad (2)$$

Where H_{radial} depends only on the local ridge spacing ρ and H_{angle} depends only on the local ridge orientation θ. Both H_{radial} and H_{angle} are defined as bandpass filters and are characterized by a mean value and bandwidth. Each image is convolved with pre-computed filters of the same size as the image. The pre-computed filter bank (labeled *PF*0, *PF*1 . . . *PFN* in Fig. 3) are oriented in eight different direction in intervals of 22.5°. To reduce the number of pre-computed filters, the algorithm assumes that the ridge frequency is constant throughout the image. The Enhanced image I_{enh} is obtained by setting, for each pixel [x,y], $I_{enh}[x,y] = PI_k[x,y]$, where k is the index of filter whose orientation is closest to $\theta_{x,y}$.

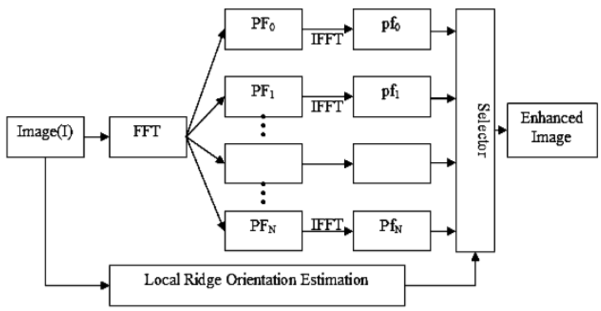

Fig. 3 Block diagram of the filtering scheme proposed by Sherlock and Monro [5]

Waston, Candela and Grother (1999) and Willis and Myers (2001) [3] proposed an interesting technique that is able to perform a sort of contextual filtering without requiring explicitly computing ridge orientation and frequency.

JOURNAL OF COMPUTING, VOLUME 2, ISSUE 11, NOVEMBER 2010, ISSN 2151-9617
HTTPS://SITES.GOOGLE.COM/SITE/JOURNALOFCOMPUTING/
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The image is divided into overlapping windows 32 X 32. Each 32 X 32 block is enhanced separately; the Fourier transform of the block is multiplied by its power spectrum raised to a power k:

$$I_{enh}[x,y]=F^{-1}\{F(I[x,y]) \times |F(I[x,y])|^{k}\} \quad (3)$$

The power spectrum contains information about the underlying dominant ridge orientation and frequency. Multiplying the FFT of the block by its magnitude a set of times has the effect of enhancing.

We adopted this approach, in addition to histogram equalization, to perform fingerprint image enhancement. To accelerate the process, we used nonoverlapping blocks. We found that the 'block' effects has no harm to the further operations and the image after consecutive binarization operation is pretty good as long as the side effect is not too severe.

2.2 Minutiae detection and false minutiae removing

Most proposed methods require fingerprint image to be converted into binary image[3,9]. The binary image is submitted to a thinning stage which reduces the thickness of the ridge to one pixel. a simple image scan allows the detection of minutiae.

The most commonly employed method of minutiae extraction is the Crossing Number (CN) concept [10]. The minutiae are extracted by scanning the local neighborhood of each ridge pixel in the image using a 3×3 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-neighborhood.

False minutiae may occur due to factors such as noisy images created by the previous processing steps (e.g. thinning). Different methods for removing false minutiae have been proposed in literature. The majority of them are based on a series of structures rules [10]. Others test the validity of each minutiae point by examining the local neighborhood around the minutiae [9], [10].

3 FINGERPRINT IMAGE PRE-PROCESSING

3.1 Segmentation

Segmentation is the process of separating the foreground regions in the image from the background regions. Separating the fingerprint area is necessary to avoid extraction of features in noisy areas of the fingerprint and background.

In a fingerprint image, the background regions generally exhibit a very low gray-scale variance value, whereas the foreground regions have a very high variance [9,10]. Hence, a method based on variance thresholding can be used to perform the segmentation. For this, the whole image is divided into blocks of size w×w and the variance of each block is computed. The variance is then compared with a threshold value. If the variance of a block is less than the threshold value, then it is deleted from the original figure. This process is carried out for the whole image. The block size is defined experimentally. We used the histogram of variance values to define the threshold value. An example of segmentation result is shown in the fig. 4.

3-2 Image Enhancement

Image enhancement techniques are often employed to reduce the noise and enhance the definition of ridges against valleys.

Fig. 4 Segmentation result

Two methods are adopted: the first one is based on Fourier Transform; the second is Histogram Equalization.

3-2-1 Fast Fourier Transform (FFT)

Each 32×32 block is enhanced separately; the Fourier transform of the block is multiplied by its power spectrum raised to a power k:

$$Ienh[x,y]= F^{-1}\{F(I[x,y]) \times |F(I[x,y])|^{k}\} \quad (4)$$

The "k" in the equation is an experimentally determined constant. While having a higher "k" improves the appearance of the ridges, filling up small holes in ridges, having too high a "k" can result in false joining of ridges. Thus a termination might become a bifurcation. We choose k = 0.45.

3.2.2 Histogram Equalization

Histogram Equalization aims to expand the pixel value distribution of an image so as to increase the perceptional information. The histogram after the histogram equalization occupies all the range 0 to 255 and the visualization effect is enhanced [4]. Fig. 5 shows the result of the image enhancement algorithms.

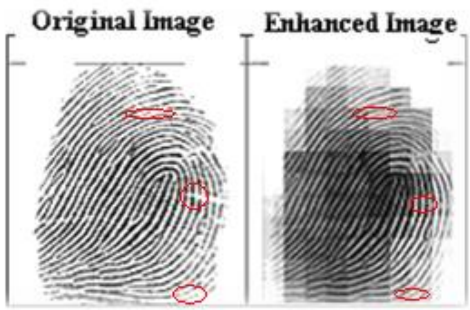

Fig. 5 Enhancement result

The enhanced image has the improvements to connect some falsely broken points on ridges and to remove some spurious connections between ridges. The side effect of each block is obvious but it has no harm to the further operations because as we will see the image after binarization operation is pretty good.

4 MINUTIAE EXTRACTION

4.1 Binarization

Most minutiae extraction algorithms operate on binary images where there are only two levels of interest: the black pixels that represent ridges, and the white pixels that represent valleys. Binarization is the process that converts a grey level image into a binary image. This improves the contrast between the ridges and valleys in a fingerprint image, and consequently facilitates the extraction of minutiae.

To obtain satisfactory results of the binarization, we divide the image into 16x16 blocks and apply a simple global threshold algorithm in each block. Within this small local area the pixel density does not vary significantly, allowing the rendering of distinct ridge contours without much blurring. Fig. 6 shows the result of binarization of the image on the fig. 5.

Fig. 6 Binarized image

4.2 Thinning

Thinning is a morphological operation that successively erodes away the foreground pixels until they are one pixel wide [9]. A standard thinning algorithm is employed, which is accessible in MATLAB via the "thin" operation under the bwmorph function.

The application of the thinning algorithm to a fingerprint image preserves the connectivity of the ridge structures while forming a skeletonised version of the binary image (fig. 7). This skeleton image is then used in the subsequent extraction of minutiae.

4.3 Minutiae Detection

Once a binary skeleton has been obtained, a simple image scan allows the pixel corresponding to minutiae to be detected. Using 3x3 windows to examine the local neighborhood of each ridge pixel if the central pixel is 1, a pixel is classified a ridge ending, bifurcation or non-minutiae point [10]:

- A ridge pixel is a ridge ending, if the number of ridge pixels in the 8-neighborhood is 1.
- A ridge pixel is a ridge bifurcation, if the number of ridge pixels in the 8-neighborhood is greater than or equal to 3.
- A ridge pixel is an intermediate ridge pixel, if the number of ridge pixels in the 8-neighborhood is 2.

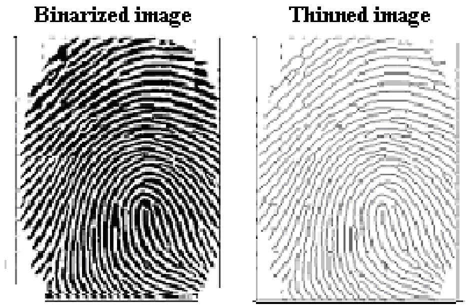

Fig. 7 Image thinning

The result of minutiae detection is shown in fig .8.

Fig. 8 Result of minutiae detection algorithm

4.4 Removing false minutiae

We use a simple method consisting of two steps. First we remove the minutiae on the borders, and then we check the validity of the minutiae by assuming a minimum distance between minutiae. Fig. 9 shows the result for removing false minutiae from fig. 8.

Fig. 9 Minutiae after removing false ones

5 EXPERIMENTAL RESULTS

The proposed method is verified with the FVC2002 database. Testing was performed first to adjust our choice for thresholds and parameters used in our algorithms. Then we tested the whole system with and without enhancement stage. Tests were performed on fingerprint images with different qualities. They show that performing image enhancement leads to significant improvement of the results. The true minutiae detection is improved by 16%.

For high quality images, a good ratio (96%) for true minutiae extraction is achieved.

6 Conclusion

In this paper, a simple yet effective fingerprint minutiae extraction approach is proposed. First fingerprint segmentation is performed to separate the fingerprint image from the background. This allowed reducing the image size to be processed by the following steps. Second fingerprint image enhancement is performed. Enhancement approach involves two algorithms: a contextual filtering based on Fourier Transform without requiring computing local ridge orientation and frequency, and Histogram Equalization. Minutiae extraction process includes Binarization, Thinning, Minutiae Detection, and finally removing false minutiae. The results obtained are quite promising where a good ratio of true minutiae detection was achieved.

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