Fingerprint Image Enhancement In Fingerprint Recognition System

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***Abstract-* Fingerprints are the oldest and most widely used form of biometric identification. The performance of any fingerprint recognizer highly depends on the fingerprint image quality. Different types of noises in the fingerprint images pose greater difficulty for recognizers. Thus, image enhancement techniques are employed prior to minutiae extraction to obtain a more reliable estimation of minutiae locations. An enhancement algorithm improves image quality and repair broken ridges.**

This paper proposes a new method of enhancing fingerprint image which improves the visual quality of the fingerprint image. The result shows, it can improve the performance of image enhancement.

Keywords: Minutiae, Fingerprint enhancement, Gabor Filter, Orientation, Minutiae Extraction

I. INTRODUCTION

Biometrics is a natural and reliable solution to identity determination problem by recognizing individuals derived from their physiological or behavioral characteristics that are inherent to the person. Physiological and behavioral characteristics that commonly used for biometric recognition are face, fingerprint, iris, retina, DNA, signature, palm print, ear, voice, keystroke dynamics, hand-geometry and gait.

The most popular and widely used bio-identification system is fingerprint recognition system because of the fact that fingerprints of human are unique and persistent**.** A fingerprint can be seen as smoothly varying pattern formed by alternating crest (ridges) and troughs (valleys) on the surface of the finger. A ridge is defined as a single curved segment, and a valley is the space between two adjacent ridges.

Generally, there are three main criteria about fingerprint:

- *Unchangeable:* Configuration and information about fingerprint pattern is permanent and never change even while body's growth process.
- *Unique:* The varieties of fingerprint ridges levels are higher. Hence, everybody have the unique fingerprint ridges even the identical twins have different fingerprint.
- *Classification:* Classification of fingerprint pattern is limited. This will make the systematic classification of fingerprint pattern easy[8].

Fingerprints have some unique features by which they are distinguished from each other. There are three types of features found in a fingerprint: level-1 features (core and delta), level 2 features (minutiae), and level 3 features (sweat pores). Out of these features, minutiae are the mostly used features for recognizing fingerprints because they mimic the way human experts recognize fingerprints. Minutiae are minute details present in the fingerprint in the form of points that either abruptly ends (ending or terminations) or fork into two branches deriving from a point (bifurcations).

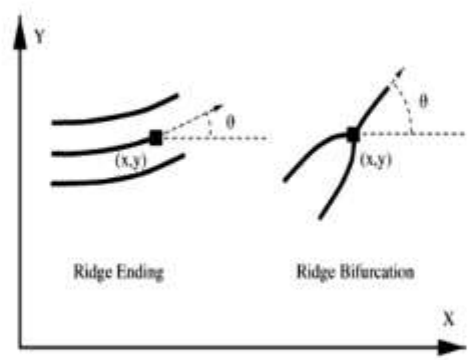

Fig. 1. Minutiae: Termination & Bifurcation[2]

II. FINGERPRINT RECOGNITION SYSTEM

A Fingerprint Recognition System usually includes enrollment module and authentication module, both modules include image processing. For the enrollment module, first, the system processes fingerprint images from user interface module. Second, a minutiae extraction algorithm is applied to the fingerprint images and the minutiae patterns are extracted. Third, an algorithm of images quality checking is necessary to ensure that the records in the minutiae database only include fingerprints of good quality. If a fingerprint image of poor quality is found, the module requires user to enroll it again. Finally, the minutiae are saved in the minutiae database. For authentication module, the first three steps are the same as enrollment module. Fourth, the minutiae pattern are fed to minutiae matcher which compare them with the person's minutiae pattern stored in the minutiae database to establish the identity.

The components of a Fingerprint Recognition System are shown in Figure 2. It includes four parts: user interface, Minutiae database, enrollment module, and authentication module.

The user interface module provides mechanisms for a user to input his/her fingerprints into the system (Fingerprints Acquisition) and also displays the matching result (Result Display). The minutiae database module is a place to store a collection of records, each of which corresponds to an authorized person that has access to the system. Each record contains user's information and their minutiae. The fingerprint enrollment module is to enroll user's information and their fingerprints into the system database, which includes image processing, minutiae extractor, image quality check and minutiae database. The fingerprint authentication module is to authenticate the identity of the person who intends to access the system, which includes image processing, minutiae extractor, image quality check and minutiae matcher[1].

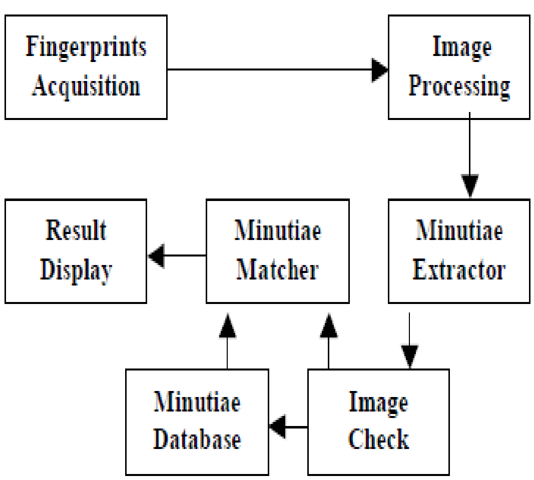

Fig. 2. Flowchart of a fingerprint recognition system[1]

Fingerprint images are rarely of perfect quality as needed. They may be degraded and corrupted with elements of noise due to many factors including variations in skin and impression conditions. This corruption & degradation can result in a significant number of spurious minutiae being created and genuine minutiae being ignored. A critical step in studying the statistics of fingerprint minutiae is to reliably extract minutiae from fingerprint images. Thus, it is necessary to employ image enhancement techniques prior to minutiae extraction to obtain a more reliable estimate of minutiae locations.

III. FINGERPRINT IMAGE ENHANCEMENT

Image enhancement is the simplest and most widely used areas of digital image processing. Enhancement is the process of manipulation of image. Different types of noise in the fingerprint images create difficulty for recognizers like environmental and technical, good quality images is very important, but due to some environmental factors like user's body condition, a significant percentage of acquired images is of poor quality in practice . From the poor quality images many unwanted minutiae may be created and many genuine minutiae may be ignored. The efficiency of fingerprint image enhancement algorithm greatly depends on the quality of the fingerprint images. In order to obtain robust performance of a finger print image enhancement algorithm, that can improve the transparency of the ridge structures, is very essential.

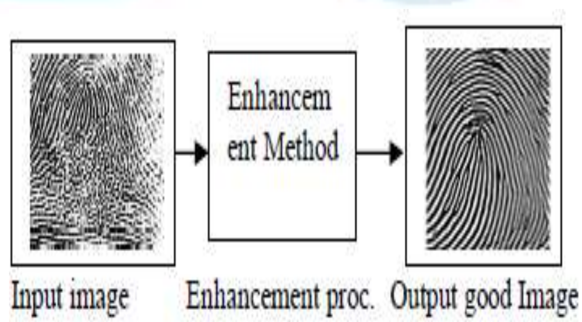

Fig. 3. Enhancement process[5]

Basically, two types of images can be considered for image enhancement process.

- *Gray Level Image:* This type of image forms a sinusoidal-shaped plane with ridges and valleys of the fingerprint image, which has a well defined frequency and orientation.
- *Binary Ridge Image:* Binary images are also called bi-level or two-level. This means that each pixel is stored as a single bit i.e. a 0 or 1.

where 0 refers to black and 1 refers to white. Minutiae extraction algorithm is used to obtain the binary ridge image from a gray level fingerprint image[7].

Image enhancement techniques are categorized into two domains.

- *Spatial Domain:* Spatial domain refers to the image plane itself, and image processing methods in this category are based on direct manipulation of pixels in an image. Spatial domain process discussed above can be denoted by the expression:

$$g\,(x,y) = T\,[\,f\,(x,y)] \qquad (1)$$

  where f (x,y) is the input image, g (x,y) is the output image and T is an operator on defined over a neighborhood of point (x,y).
- *Frequency Domain:* Frequency domain consists of modifying the Fourier transform of an image and then computing the inverse transform [Discrete Fourier Transform (DFT)] to get back to input image .Thus given a digital image f (x,y), of size M x N, the basic filtering equation in which we are interested has the form:

$$g\,(x,y) = \Im^{-1}\,[\,H\,(u,v)\,F\,(u,v) \qquad (2)$$

  where $\Im$-1 is the IDFT, F (u,v) is the DFT of the input image f (x,y), H (u,v) is the filter function and g (x,y) is the filtered output image. Specification of H (u,v) is simplified considerably by using functions that are symmetric about the center. This is accomplished by multiplying the input image by $(-1)^{x+y}$ prior to computing its transform[5].

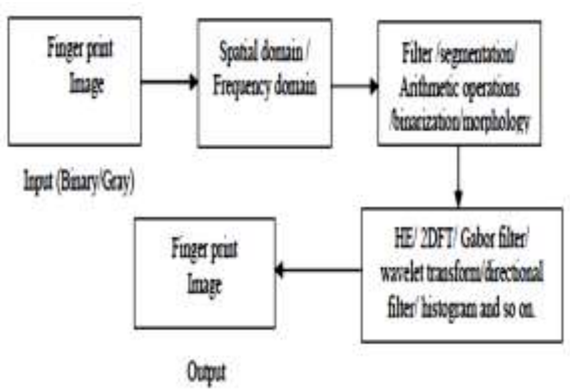

Fig. 4. Stages of image enhancement process[7]

A fingerprint expert is often able to correctly identify the minutiae by using various visual clues such as local ridge orientation, ridge continuity, ridge tendency, etc., as long as the ridge and valley structures are not corrupted completely. It is possible to develop an enhancement algorithm that exploits these visual clues to improve the clarity of ridge structures in corrupted fingerprint images.

Generally, for a given digital fingerprint image, the region of interest can be divided into the following three categories:

- *Well-defined region*, where ridges and valleys are clearly differentiated from one another such that a minutiae extraction algorithm is able to operate reasonably.
- *Recoverable corrupted region*, where ridges and valleys are corrupted by a small amount of creases, smudges, etc. But, they are still visible and the neighboring regions provide sufficient information about the true ridge and valley structures.
- *Unrecoverable corrupted region*, where ridges and valleys are corrupted by such a severe amount of noise and distortion that no ridges and valleys are visible and the neighboring regions do not provide sufficient information about the true ridge and valley structures either.

The first two categories of regions are referred to as recoverable and the last category as unrecoverable. The goal of an enhancement algorithm is to improve the clarity of ridge structures of fingerprint images in recoverable regions and to remove the unrecoverable regions. Since the objective of a fingerprint enhancement algorithm is to improve the clarity of ridge structures of input fingerprint images to facilitate the extraction of ridges and minutiae, a fingerprint enhancement algorithm should not result in any spurious ridge structures. This is very important because spurious ridge structure may change the individuality of input fingerprints[2].

IV. FINGERPRINT IMAGE ENHANCEMENT ALGORITHM

The proposed image enhancement method includes following step:

A. Image Normalization:

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. Normalization does not change the ridge structures in a fingerprint; it is performed to standardize the dynamic levels of variation in grey-level values, which facilitates the processing of subsequent image enhancement stages.

I(i,j) represent the grey-level value at pixel (i,j), and N(i,j) represent the normalized gray-level value at pixel (i,j). The normalized image is defined as:

$$N(i,j)=\begin{cases} M_0 + \sqrt{\frac{V_0(I(i,j)-M)^2}{V}} & \text{if } I(i,j)>M \\ M_0 - \sqrt{\frac{V_0(I(i,j)-M)^2}{V}} & \text{otherwise} \end{cases} \quad (3)$$

where M and V are the estimated mean and variance of I(i,j), respectively, And M_0 and V_0 are the desired mean and variance values, respectively.

B. Image Orientation Estimation:

The orientation field of a fingerprint image defines the local orientation of the ridges contained in the fingerprint[3].

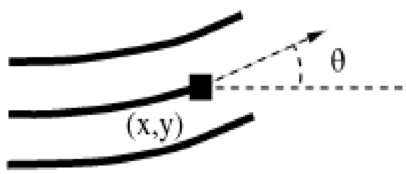

Fig. 5. The orientation of a ridge pixel in a fingerprint[2]

The steps for calculating the orientation at pixel (i,j) are as follows:

1). Firstly, a block of size wXw is centered at pixel (i,j) in the normalized fingerprint image.

2). For each pixel in the block, compute the gradients dx(i,j) and dy(i,j),which are the gradient magnitudes in the x and y directions, respectively.

The horizontal Sobel operator is used to compute dx(i,j) :

$$dx=\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \quad (4)$$

The vertical Sobel operator is used to compute dy(i,j):

$$dy=\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad (5)$$

The local orientation at pixel (i,j) can then be estimated using the following equations:

$$Vx(i,j)= \sum_{u=i-\frac{w}{2}}^{u=i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{v=j+\frac{w}{2}} 2 * dx(u,v) * dy(u,v) \quad (6)$$

$$Vy(i,j)= \sum_{u=i-\frac{w}{2}}^{u=i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{v=j+\frac{w}{2}} d^2x(u,v) * d^2y(u,v) \quad (7)$$

$$\Theta(i,j) = \frac{1}{2} tan^{-1}\left(\frac{Vy(i,j)}{Vx(i,j)}\right) \quad (8)$$

where Θ(i,j) is the least square estimate of the local orientation at the block centered at pixel (i,j).

3). Smooth the orientation field in a local neighborhood using a Gaussian filter. The orientation image is firstly converted into a continuous vector field, which is defined as:

$$\varphi_x(i,j) = \cos(2\Theta(i,j)), \quad (9)$$

$$\varphi_y(i,j) = \sin(2\Theta(i,j)), \quad (10)$$

where φ_x and φ_y are the x and y components of the vector field, respectively. After the vector field has been computed, Gaussian smoothing is then performed as follows:

$$\varphi_x^{'}(i,j) = \sum_{u=-w_\varphi/2}^{w_\varphi/2} \sum_{v=-w_\varphi/2}^{w_\varphi/2} (G(u,v) * \varphi_x(i-uw, j-vw)) \quad (11)$$

and

$$\varphi_y^{'}(i,j) = \sum_{u=-w_\varphi/2}^{w_\varphi/2} \sum_{v=-w_\varphi/2}^{w_\varphi/2} (G(u,v) * \varphi_y(i-uw, j-vw)) \quad (12)$$

where G is a Gaussian low-pass filter of size wΦXwΦ.

4). The final smoothed orientation field O at pixel (i,j) is defined as:

$$O(i,j)=\frac{1}{2} tan^{-1}\left(\frac{\varphi_y^{'}(i,j)}{\varphi_x^{'}(i,j)}\right) \quad (13)$$

C. *Orientation Map Improvement:*

The method used here tries to improve orientation estimation in heavy noise and broken-ridge areas. It also tries to preserve the orientation values of singular points area.

A 2-D low-pass Gaussian is used to modify the rough local ridge orientation. The weighted averaging is computed for two ranges of orientation values separately.

For 45° > O(u,v) >135°, the vertical weight W_v, and the vertical weighted mean factors M_v in w×w blocks is computed as,

W_v(i,j)=$\sum_u \sum_v dy(u,v) * N(u-i, v-j)$ (14)

M_v(i,j)=$\sum_u \sum_v O(u, v-z) * dy(u,v) * N(u-i, v-j)$ (15)

$$z = \begin{cases} 0, & \text{if } O(u,v) < 45^o \\ \pi, & \text{otherwise} \end{cases} \quad (16)$$

and, for 45º < O(u, v) < 135º, horizontal weight W_h, and horizontal weighted mean factors M_h in wxw blocks is computed as,

W_v(i,j)=$\sum_u \sum_v dx(u,v) * N(u-i, v-j)$ (17)

M_v(i,j)=$\sum_u \sum_v (O(u,v) * dx(u,v) * N(u-i, v-j))$ (18)

Finally filtered orientation is calculated using weighted mean:

$$O_f(i,j) = \begin{cases} \frac{M_v(i,j) * W_v(i,j) + (M_h(i,j)+\pi) * W_h(i,j)}{W_v(i,j) + W_h(i,j)}, & \text{if } M_d(i,j) > \frac{\pi}{2} \\ \frac{M_v(i,j) * W_v(i,j) + (M_h(i,j)+\pi) * W_h(i,j)}{W_v(i,j) + W_h(i,j)}, & \text{if } M_d(i,j) <= \frac{\pi}{2} \end{cases} \quad (19)$$

M_d(i,j)= M_v(i,j)- M_h(i,j) (20)

where i - $\frac{w}{2}$ <=u, v<=i + $\frac{w}{2}$

D. Gabor Filteration:

The band pass filter i.e. tuned to the corresponding frequency and orientation can effectively remove the undesired noise and preserve the true ridge and furrow structures. Gabor filters have both frequency-selective and orientation-selective properties and have optimal joint resolution in both spatial and frequency domains. Therefore, it is appropriate to use Gabor filters as band pass filters to remove the noise and preserve true ridge/valley structures[6].

H(x,y,O_f, f)=exp($\frac{1}{2}(\frac{x^2}{\nabla x} + \frac{y^2}{\nabla y}$))cos(2$*$ O_f $*$f*x*cosO_f) (21)

where x'=xsin(O_f)+ycos(O_f)
and
y'=xcos(O_f)- ysin(O_f).

O_f is the orientation image, ∇x and ∇y are Gaussian envelope which are both set up by the test images. Finally Enhanced Image E is obtained using the above Gabor filter H and normalized image N.

V. RESULT AND DISCUSSION

The system captures the fingerprint original images. Initially some pre-processing is performed on the image as per the requirement. Then image normalization (3) is carried out. In second step, the ridge orientation formulae (8), (13), (19) are applied into the normalized image and a fingerprint ridge orientation map is obtained. Then a Gabor Filter (21) is used for image enhancement, this Gabor filter can reduce the noise, provides more accurate distance between the two ridges for the further processing. After applying above steps of proposed method, more number of genuine ridge endings and ridge bifurcations are extracted as compared to the enhancement algorithm proposed by Shunshan Li et al.[1].

Following result is obtained by implementing the proposed enhancement algorithm.

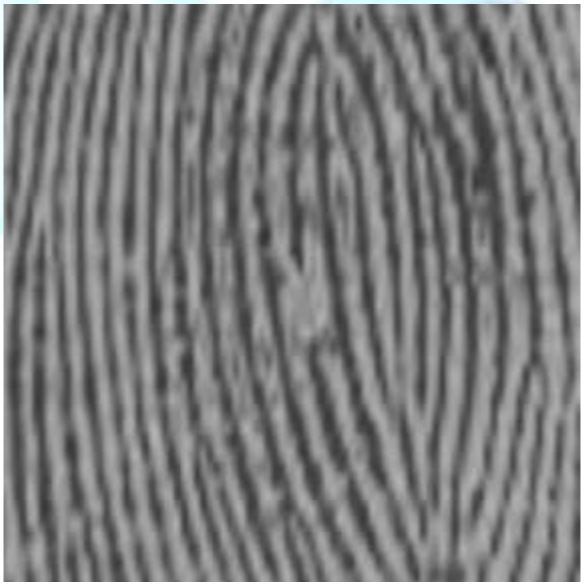

Fig. 6. Input Image

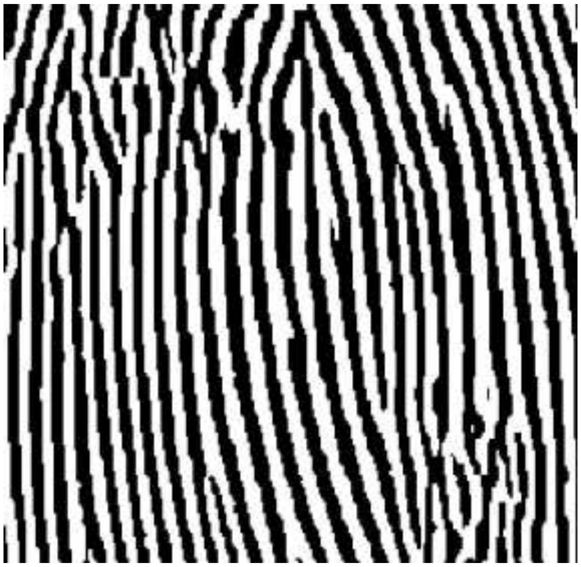

Fig. 7. Enhanced Output Image

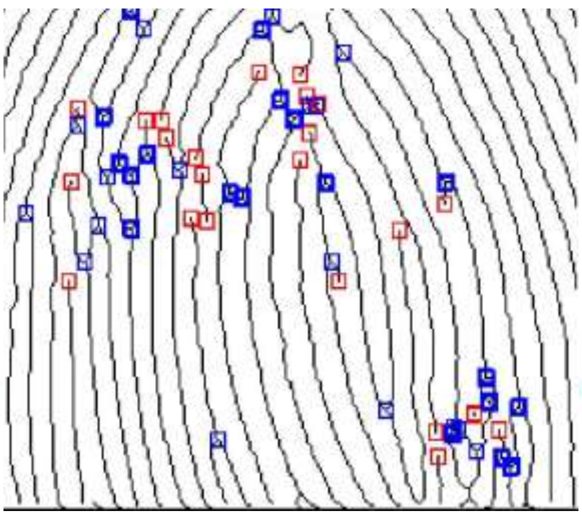

Fig. 8. Extracted Minutiae

VI. CONCLUSION AND FUTURE WORK

In this paper a fingerprint image enhancement method is introduced, it includes image normalization, ridge orientation estimation, a Gabor filter processing. Gabor filter enhances the ridge, connects the ridge breaks and ensures the maximal gray values of the image being located at the ridge center. Furthermore, this method does not result in any spurious ridge structure, which avoids undesired side effects for the subsequent processing and provides a reliable fingerprint image processing for Fingerprint Recognition System.

The future work includes that the development of the new solution of the enhancement algorithm to reduce the noise from the image and increase the computation speed using combined method and efficient filter.

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