An Effective Method for Forensic Latent Fingerprint Enhancement and Dictionary Construction

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***Abstract*— Latent fingerprints are fingerprints which have very low quality due to unclear ridge structure, uneven contrast or overlapping patterns. Latent fingerprints play a crucial role in identifying criminals in many cases. So an effective method to enhance latent fingerprint is necessary to identify the actual culprits. In this method, latent fingerprint is enhanced based on prior knowledge of fingerprint structure. Prior knowledge of fingerprint structure is represented by a dictionary of reference orientation patches. For that dictionary of reference orientation patches is constructed using a set of orientation fields, which is extracted from high quality fingerprints. For estimating the orientation field of latent fingerprint, ridge orientation and ridge frequency are estimated.**

***Keywords*— Latent fingerprints, Ridge structure, Orientation patches, Orientation fields, Ridge orientation, Ridge frequency.**

I. INTRODUCTION

Fingerprints are unique identifiers of individuals. Fingerprints are even more unique than Deoxyribonucleic Acid (DNA), the genetic material in each of our cells. Although identical twins can share the same DNA, they can't have the same fingerprints. A fingerprint is made up of a number of ridges and valleys on the surface of the finger. Each ridge contains pores, which are attached to sweat glands under the skin. Ridges are the upper skin layer segments of the finger. Valleys are the lower skin layer segments of the finger that represents space between the ridges. The ridges form minutiae points, major minutiae features of fingerprints are ridge endings, ridge bifurcations and short ridge or dot. The ridge ending is the point at which a ridge terminates. Bifurcations are points at which a single ridge splits into two ridges. Short ridges are ridges which are significantly shorter than the average ridge length on the fingerprints. Other minutiae features of fingerprints are islands where ridges occupying a middle space between two temporarily divergent ridges, ponds or lakes in which empty spaces between two temporarily divergent ridges, spurs where a notch projecting from a ridge, bridges where small ridges joining two longer adjacent ridges, and crossovers where two ridges which cross each other. All ridges of fingerprints form patterns. The three basic fingerprint patterns are loops, whorls or arches. (i)Loop : Ridges enter from one side of a finger, form a curve, and then exit on that same side. There are two types of loops: Radial loops slope toward the thumb, while Ulnar loops **s**lope toward the little finger. (ii) Whorl : Ridges form circularly around a central point on the finger. (ii) Arch : Ridges enter from one side of the finger, rise in the center forming an arc, and then exit on other side of the finger.

Minutiae features and fingerprint patterns are very important in the analysis of fingerprints since no two fingers have been found to be identical. The uniqueness of a fingerprint can be determined by the pattern of ridges and furrows as well as the minutiae points. Benefits of fingerprint biometric systems are that they are easy to use, cheap, small size, low power, non- intrusive and also large database of fingerprints are available.

Latent fingerprints refer to impressions unintentionally left on the surface of an object or wall. Latent fingerprints may consist of a small portion of the surface of a finger. Most of the latent fingerprints are of poor quality due to unclear ridge structure, uneven contrast or overlapped by handwriting, printed letters or by other fingerprints. Latent fingerprints are the most important source of evidence in crime scene investigation to identify and convict the suspects. Due to poor quality of latent fingerprints, latent fingerprint enhancement is still a challenging problem.

A. Related Works

Due to the poor quality of latent fingerprint, ridge orientation estimation of latent fingerprint is still a challenging problem. In Automatic Fingerprint Identification System (AFIS), Yuliang He *et.al.* [2], proposed ridge orientation estimation method based on difference on mean value of possible ridge directions. To overcome the difficulty in estimating possible ridge direction of latent fingerprints, Sharat Chikkerur *et.al*. [3] proposed a method based on Short Time Fourier Transform (STFT) analysis, which was able to yield the local ridge orientation, region mask and ridge frequency information simultaneously. Soweon Yoon *et.al.* [4] further improved the ridge orientation estimation using hypothesis generation method. Although the need for manual mark-up is minimised in this method, it was difficult to assess the quality of the latents automatically. Soweon Yoon *et.al.* [5] proposed another method for ridge orientation estimation

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based on skeleton of fingerprint images which is generated by a commercial fingerprint Software Development Kit (SDK), and true ridge orientation is obtained by regularization. Anil K. Jain and Jianjiang Feng [6] proposed a region growing algorithm to reliably estimate the ridge direction and frequency of latent fingerprints. To estimate component orientation fields from overlapped fingerprints, Jianjiang Feng *et.al*. [7] proposed a method based on constrained relaxation labelling.

In this paper, latent fingerprint identification is based on dictionary of reference fingerprint patches. In this method, the reference fingerprints are preprocessed for dictionary construction stage and latent fingerprint are enhanced after estimating ridge orientation and ridge frequency. Enhanced latent fingerprint are used for fingerprint identification, which is carried out based on dictionary of reference orientation patches.

This paper is structured as follows. In section II, block diagram for dictionary construction stage is discussed, which include fingerprint image enhancement and orientation patch construction. The steps for latent fingerprint image enhancement are described in Section III. Section IV compliments the results with discussions. Conclusions are finally drawn in section V.

II. DICTIONARY CONSTRUCTION STAGE

In dictionary construction stage, high quality fingerprints with clear ridge structures are used. Such good quality reference fingerprints are enhanced using gabor filters. Filtering process removes the noise present in images and preserves the true ridge or valley structures. After fingerprint image enhancement, orienation patches of b × b block size are constructed. Set of orientation patches forms dictionary which preserves the orientation elements of reference fingerprints. Block diagram for dictionary construction stage is shown in Fig 1.

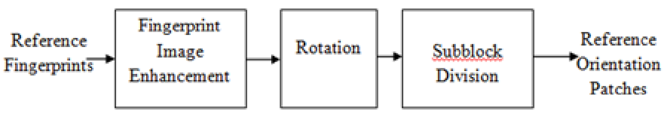


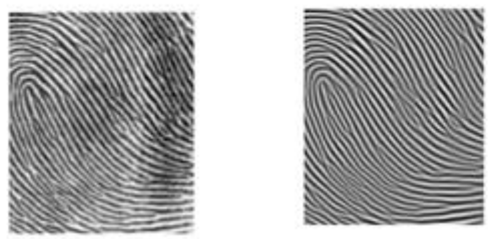
Fig 1.Block diagram of dictionary construction stage.

There are two main steps for dictionary construction : fingerprint image enhancement and orientation patch construction. Fingerprint orientation field is comprised of orientation patches which are further comprised of orientation elements. The dictionary consists of a number of orientation patches of same size. Each orientation patches are of block size 16 × 16 pixels. Input to the system is a set of high-quality fingerprints. They are called reference fingerprints. High quality fingerprints are used to ensure that the dictionary consist of valid orientation patches.

Algorithm for dictionary construction stage:
(i) Selection of input reference fingerprints for dictionary construction.
(ii) Selection of orientation for gabor filter.
(iii) Selection of frequency of harmonic function.
(iv) Filtering the input images based on selected orientation and frequency.
(v) Rotation of enhanced image in different angles.
(vi) Sub blocking each rotated image into blocks of size 16 × 16.

A. Fingerprint Image Enhancement

Reference images are enhanced by gabor filter. Image enhancement is used for gray level & contrast manipulation, noise reduction etc. Frequency and orientation representation of gabor filters are similar to those of human visual system and they have been found to be particularly appropriate for texture representation and discrimination. Fig 2 shows the original input image and its enhanced image.



(a) (b)

Fig 2 (a) original input image and (b) enhanced image

Gabor filters play an important role in many application areas for the enhancement of various types of images and feature extraction. The impulse responses of these filters are created by multiplying a Gaussian function with a sinusoidal function. By extending these functions to two dimensions, it is possible to create filters which are selective for orientation; i.e., in the spatial domain, a 2D Gabor filter is a Gaussian function modulated by a sinusoidal wave. For the purpose of enhancing curved structures in noisy images, Gabor filters locally adapt their shape to the direction of flow. Gabor filters could be able to remove the noise without creating artifacts in the enhanced image.

By tuning gabor filter to specific frequency and direction, the local orientation and frequency information can be obtained for each region in the input image. Its impulse response is defined by a sinusoidal wave multiplied by a Gaussian function. The impulse response of a gabor filter is given by

$$G(x, y, f, \theta) = \exp\left\{-\frac{1}{2}\left(\frac{x'^2}{\delta x^2} + \frac{y'^2}{\delta y^2}\right)\right\}\cos(2\pi f x') \quad (1)$$

$$x' = x\sin\theta + y\cos\theta \quad (2)$$

$$y' = x\cos\theta - y\sin\theta \quad (3)$$

where θ controls the orientation of filtering, f represents frequency of sinusoidal wave, δx and δy are the variances of gaussian envelop along x and y axes.

B. Orientation Patch Construction

After enhancement of reference fingerprints, enhanced image is rotated in different angles. The significance of image rotation is that the directions of latent fingerprints are unknown. So enhanced image is rotated in 21 different angles with 5^0 differences. After rotating each enhanced image, orientation patches are obtained by subdividing each orientation image into block of size 16 × 16 pixels. Each orientation patches preserves the orientation elements of reference fingerprints.

III. LATENT FINGERPRINT ENHANCEMENT

A single latent fingerprint image contains regions of good, medium and poor quality, where the ridge pattern is very noisy and corrupted. If a single gabor filter is used for entire fingerprint image enhancement, it may cause a large number of genuine minutiae are to be missed. So it is difficult to enhance latent fingerprint by single gabor filter. In this technique, ridge and valley structures of input latent fingerprint images are estimated based on local ridge orientation and frequency [11]. Local ridge orientation is usually specified for a block rather than at every pixel. For that, input image is divided into w × w non-overlapping blocks, region mask and local ridge orientation is found for each block. Latent fingerprint enhancement is based on four processes: normalization, local orientation estimation, local frequency estimation and region mask generation.

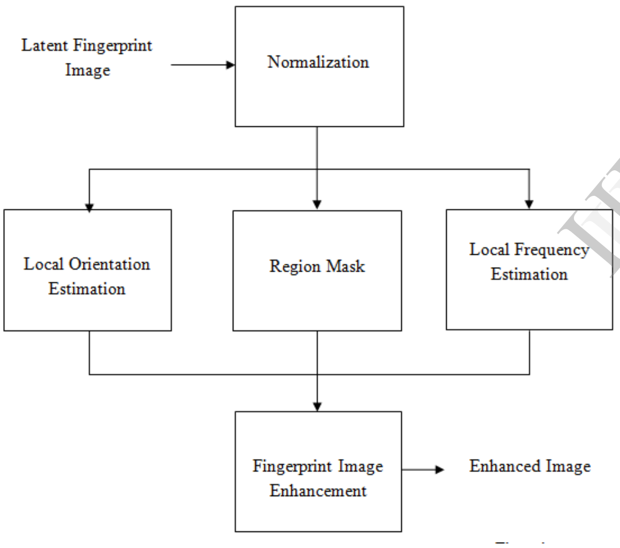
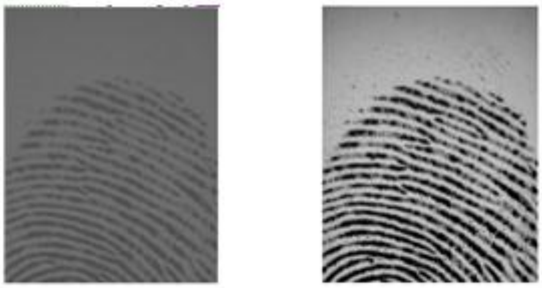


Fig 3. Block diagram of latent fingerprint enhancement

A. Normalization

Normalization is a pixel-wise operation. It does not change the clarity of the ridge and valley structures. The main purpose of normalization is to reduce the variations in gray-level values along ridges and valleys. A latent fingerprint image is normalized based on mean and variance. Fig 4 shows the latent fingerprint image and normalized image.



(a) (b)

Fig 4. (a) Latent fingerprint image and (b) normalized image

The original image is latent due to uneven contrast and the presence of broken ridges. Such an image is subjected for normalization.

Steps for image normalization:

(i) Mean value of the input image is computed.

(ii)Variance of input image is computed which gives variation of each pixel from its
mean.

(iii) Input image is normalized to desired mean and variance.

Input image is latent due to unclear ridge structure and missing of ridge structures. Let I denotes the input latent fingerprint which is a M × M matrix, where A(i, j) represents the intensity of the pixel at the i^{th} row and j^{th} column. The mean and variance of a latent fingerprint image I, are defined as,

$$\text{mean}(A) = \frac{1}{N^2}\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} A(i,j) \qquad (4)$$

$$\text{variance}(A) = \frac{1}{N^2}\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\{A(i,j) - \text{mean}(A)\}^2 \qquad (5)$$

Then, normalized image N(i, j) is given by,

$$N(i,j) = \begin{cases} \mu_0 + \sqrt{\dfrac{V_0(A(i,j)-\text{mean})^2}{\text{variance}}} & \text{If } A(i,j) > \text{mean} \\ \mu_0 - \sqrt{\dfrac{V_0(A(i,j)-\text{mean})^2}{\text{variance}}} & \text{Otherwise} \end{cases} \qquad (6)$$

where μ_0 represent desired mean and V_0 represents desired variance values.

B. Local Orientation Estimation

An orientation image O is defined as an N × N image, where O(i, j) represents the local ridge orientation at pixel (i, j). The orientation image is estimated from the normalized input fingerprint image. Fig 5 shows the orientation plotted on original image.

Fig 5. orientation plotted on original image

Steps for ridge orientation estimation:
(i) Image gradient of normalized image is computed.
(ii) Covariance of image gradients is calculated which gives the principal axis of
variation in image gradients.
(iii) Orientation for each local image block are computed using principal axis of variation in image gradients.
The orientation image represents direction of ridges and valleys in a local neighbourhood. Initially, normalized image is divided into blocks of size 16 × 16 and image gradients are calculated which gives the direction of pixels in each blocks. Then the local ridge orientations are estimated at each pixel from principal axis of variation in the image gradients. Finally, the local ridge orientation, O(i, j) is computed using the equation,

$$O(i,j) = \frac{1}{2}\tan^{-1}\left(\frac{\partial f}{\partial y}, \frac{\partial f}{\partial x}\right) \quad (7)$$

Where O(i, j) represents the estimated ridge orientation, $\frac{\partial f}{\partial y}$ and $\frac{\partial f}{\partial x}$ represents derivative of image gradients along x and y axes.

C. Local Frequency Estimation

Local frequency estimation is used to estimate average inter ridge distance within each block. For each blocks of images, ridge frequency is estimated based on projection sum taken along the direction orthogonal to ridges. Distance between any two maximum points provide average inter ridge distances and ridge frequency can be obtained using the equation,

$$F(i,j) = \frac{1}{D(i,j)} \quad (8)$$

Where F(i, j) represents the estimated ridge frequency and D(i, j) represents distance between the two peaks.

D. Region Mask Generation

The region mask R, is defined as N × N image with R(i, j) indicating the category of the pixel. A pixel could be either a non-ridge and non-valley, i.e., unrecoverable pixel which have value zero or a ridge and valley, i.e., recoverable pixel with value one. Region mask is also specified block-wise. The region mask is obtained by classifying each block in the normalized input fingerprint image into a recoverable or a unrecoverable block. For that, ridge like regions are identified based on threshold value and value 1 is assigned for ridge like regions and value 0 for non-ridge regions.

E. image Enhancement

Based on estimated ridge orientation, region mask, ridge frequency, normalized image is enhanced using gabor filters. Gabor filters adapt their shape to the direction and frequency as specified by estimated ridge orientation and ridge frequency.

IV. RESULTS AND DISCUSSIONS

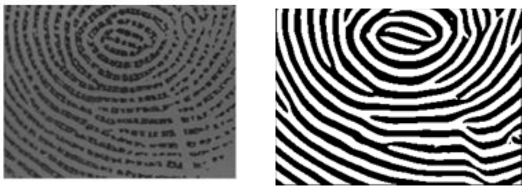
Reference fingerprints are processed in dictionary construction stage and the latent fingerprints are used in its enhancement stage. MATLAB R2010a version is used for simulation. Database for high quality fingerprints and latent fingerprints are collected from the Hong Kong Polytechnic University. Database used is POLY U HRF image database.

A. Dictionary Construction

Reference fingerprints are sets of high quality fingerprints whose ridge and valley structures are clear. Reference fingerprint images are used for constructing dictionary of reference orientation patches. Reference fingerprint images are captured using fingerprint sensors. These are gray scale images, each having the size 320 × 240. Dictionary construction utilizes high quality fingerprints whose ridge and valley structures are clear. These fingerprints are called reference fingerprints. The first step in dictionary construction is image enhancement. Reference fingerprints are enhanced using gabor filters. Gabor filtering depends upon orientation θ and frequency f. Orientation for filtering is selected as π/3 and frequency of sinusoidal wave is selected as 16. For selected orientation and frequency, gabor filter locally adapt to the direction of ridge flow. Noises present in input image are removed. Enhanced image has true ridge or valley structure of input image. Each enhanced image is rotated in different angles. Since directions of latent fingerprints are unknown, enhanced images are rotated in 21 different angles with 5^0 differences. Each rotated images are resized so that it is divisible by 16 and is subdivided into patches of size 16 × 16 pixels. Each row has 20 patches and each column has 15 patches. Each patch preserves the ridge orientation of reference fingerprints.

B. Latent Fingerprint Enhancement

Latent fingerprints are fingerprints whose ridge structures are not clear due to uneven contrast, broken ridges etc. On such fingerprints, image enhancement is done. Latent fingerprint images considered are gray scale images with size 320 × 240. This image is latent due to broken ridge structure in the right half of the image. This image is given to the enhancement stage for further processing. Latent fingerprints can be enhanced by knowing local orientation and local frequency of each region of the image. The first step for latent fingerprint enhancement is image normalization. Input latent fingerprint image is normalized based on its mean and variance. For image normalization, mean and variance of the input image are found. Mean of the input image under discussion is obtained as 84.8329 and standard deviation of the input image is obtained as 23.4047. Based on these values, large variation in gray values along ridges and valleys of input latent fingerprint is reduced. Normalized image has gray values in the range of -2.6351 and 1.5091. From the normalized image, local orientation is found out. From the normalized image, image gradients Gx and Gy, are computed along x and y direction. Gx and Gy are in the range of [-0.9904, 0.9452] and [-0.9757, 0.9755] respectively. Using this image gradients, covariance of the image gradients are computed which gives principle axis variation of each image gradients. Ridge orientation is found using covariance measure and is obtained in the range of [2.3687, 3.1416]. It is plotted on normalized image. From the normalized image, median frequency for entire image is obtained as 0.0806 and generated mask had value 1 for recoverable fingerprint region and value 0 for nonrecoverable fingerprint region. Finally, latent fingerprint is enhanced using gabor filters. Fig 6 shows the input latent image and its enhanced image.



(a) (b)

Fig 6. (a) Latent fingerprint image and (b) enhanced image

V. CONCLUSION

Fingerprint identification is the method of identification using the impressions made by the minutiae ridge formations or patterns found on the fingertips. No two persons have exactly the same arrangement of ridge patterns, and the patterns of any one individual remain unchanged throughout life. Thus, fingerprints offer a faultless means of personal identification. In dictionary construction stage, reference fingerprints are enhanced using gabor filters. Gabor filters could remove the undesired noise and preserve the true ridge or valley structure. Since latent fingerprint are corrupted, enhancement using a single gabor filter cannot be applied for entire image. Latent fingerprints are enhanced based on ridge direction, ridge frequency and region mask. Image enhancement process made the image clearer than the original image and increases the contrast between ridges and furrows.

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