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Automated Enhancement of Compromised Fingerprint Images

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Abstract

Forensic Science is a branch of science used for criminal investigations. It provides scientific evidence to prove a suspect in the court. Friction ridges of a human finger leave an impression on any surface, which encounters it, which is a fingerprint. As fingerprints can be identified uniquely, so from years it is a popular biometric way of identifying offenders. A collection of fingerprints from a crime scene is an important procedure of forensic science. Besides, images collected from crime scene usually are of poor quality that is why automatic and reliable extraction of the identifiable points (minutiae) is a difficult task for an automated system. The performance of these systems relies on the quality of fingerprints. In order to cope with this issue, the system being proposed enhances the images so they can be used further for purpose of identification through an automated system. For sake of enhancement, images are first normalized so that variations in gray levels are reduced. In the second step, orientations and frequency of ridges are estimated. These two parameters are used in the construction of a Gabor filter, which is a Gaussian kernel, consisting of a particular orientation and frequency sine wave. A properly tuned Gabor filter preserves the ridge structures and reduces noise, effectively. After this, the image is binarized so it consists of only two color values, black for ridges and white for valleys. At the end, skeletonization is applied on fingerprints so that their ridge structure is obtained. The proposed method effective and efficient results and can be considered as a pre-process of fingerprint matching for low quality fingerprints, especially collected from crime scenes. Moreover, this method can be an alternative for chemical fingerprint enhancement methods.

Keywords: *Forensic Science, Fingerprint Identification, Fingerprint Image Enhancement, Image Processing, Gabor Filtering, Binarization, Skeletonization*

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1. Introduction

Different features such as height can identify individuals, face, eyes and DNA but all these features can be altered or two persons can have identical features. To cope with this issue fingerprints are the solution, which is most widely used to identify individuals uniquely. A fingerprint consists of ridges and valleys. Ridges contain a unique pattern and characteristics, for every fingerprint, that can be identified as minutiae points. Manual identification by forensics experts had been performed since 1891 (Lee *et al.*, 2001). As the population grew day by day, manual identification became a difficult task. Therefore, a system was required to perform automated identification of fingerprints. To perform a comparison of minutiae points automated fingerprint identification system is used. A total eighteen different types of minutiae points have been identified (Lee *et al.*, 2001). The most frequent and easily identifiable minutiae points are bifurcations and ridge endings. Ridge endings are the points ending unanticipated. Bifurcation is the minutiae point where a ridge splits in a continuous way to form two ridges. The structure of these points can be seen in Figure 1. A high-quality fingerprint contains 40-100 ridge endings and ridge bifurcations (Hong *et al.*, 1998). Performance and quality of an automated system depend on the reliable extraction of these points. The quality of fingerprints can vary depending upon the work conditions, age and acquisition devices such as scanners and cameras. Besides having an efficient minutiae extraction algorithm, it is still a problem to extract minutiae points with accuracy and reliability. In such situation, an efficient fingerprint enhancement algorithm is necessary so that ridge structure is improved. A compromised fingerprint usually contains three types of regions. Well defined, recoverable and unrecoverable. A well-defined region is where ridge structure and orientations are clearly visible. A little amount of noise may be available. The recoverable region is that part where noise is present in form of smudge or creases and the ridges seem missing or very unclear. The unrecoverable region is where the severe amount of noise is present and orientations of ridges are unidentifiable. Figure 2 illustrates these three types of regions. Sometimes a forensic expert may be able to identify the ridge structure by analysis of visual clues such as tendency, continuity and orientations of ridges in a noisy and poor quality image. Proposed algorithm relies on these visual clues for the purpose of enhancement of fingerprints and refers first two types of regions in fingerprints because unrecoverable region have a very large amount of noise and it is not even possible for the human eye to identify the correct structure of ridges.

Researchers have proposed number of techniques to enhance the fingerprints. Some of these techniques use ridge characteristics for recovery of the fingerprint (Hong *et al.*, 1998; Chikkerur *et al.*, 2007; Jea and Govindraju, 2005). While other use some filtering techniques in spatial and frequency domain (Greenberg *et al.*, 2000; Misra *et al.*, 2012). Enhancement can be performed on two types of fingerprint images. (i) Binary Image or (ii) Grayscale Image. A binary image can be obtained from a grayscale image by extracting ridges. Any operation performed on binary images is efficient as there is only binary data in images and spurious ridges can be easily identified and removed. But binary images have their own limitations as extraction of ridges from the grayscale image is often not reliable and often it can cause some information loss in ridges structure. In the case of grayscale fingerprint images, ridges and valleys create a sinusoidal-shaped wave in a local neighborhood. This wave has a specific frequency and orientation. Different algorithms have been proposed based on these two factors for the purpose of grayscale fingerprint enhancement. All these approaches assume the ridges structure on the basis of their orientations. However, these assumptions cannot be valid when we have a distorted or noisy image with poor quality.

Chikkerur *et al.* (2007) proposed a fingerprint enhancement technique on the basis of Short Time Fourier transform (STFT) Analysis algorithm and determine all the essential characteristics of fingerprints. Ridge frequency and orientations are estimated simultaneously using STFT and region masks are generated to segment fingerprints. Greenberg *et al.* 2000 also proposed two methods for the enhancement of fingerprints. The first method uses histogram equalization, Wiener filtering, and image binarization, and is applicable for binary images. The second method uses an anisotropic filter and is applicable for grayscale images. The technique proposed by Jea *et al.* 2005 use features that are derived from relative minutiae information. Quality maps are generated by going through low contrast areas, low flow blocks, and high curve regions. A binary map of the fingerprint image is obtained by application of rotated grid on ridge map. Misra *et al.* 2012 proposed fingerprint enhancement by equalizing image intensity histogram and producing contrast between ridges and furrow. Hong *et al.* 1998 presented the most extensively used technique to enhance the fingerprint image. Local ridge orientation and ridge frequency are used in this technique to enhance fingerprint ridge structure. The image is first normalized and then segmented so that unrecoverable region is separated from the well-defined and recoverable region. The main step in this technique is the use of Gabor filter to reduce the noise and extract original ridge structure under small noisy or distorted area. This technique works well for corrupted or poor quality images and the unrecoverable region is removed so that it is not included in the further processing of minutiae extraction and matching.

The technique proposed in this paper performs the enhancement using Gabor filter. Images are first normalized so that their intensity values lie within desired range. After this, Eight Gabor filters are applied to recover the ridge structure and to remove noise, which is tuned with orientations of 0^o – 157.5^o with a gap of 22.5^o. The frequency used in these Gabor filters is 60 cycles per image width. For further enhancement, images are binarized using a multilevel threshold to make a clear distinction between ridges and valleys. Finally, skeletonization is applied so that a one-pixel wide structure of ridges is obtained.

2. Materials and Methods:

Several methods of image processing can cause a different impact on fingerprint images. Different techniques are explained here which are most commonly used in the field of fingerprint enhancement. These techniques are used separately and also in the form of combination, causing a different result. This technique is applied on Fingerprint Verification Competition (FVC) 2004 databases (Maltoni *et al.*, 2009). It consists of approximately 3500 fingerprints with four databases. Each database has a different method for acquisition of fingerprints. DB1 consists of fingerprints obtained using an optical sensor "V300" by CrossMatch. DB2 consists of fingerprints obtained using an optical sensor “U.are.U 4000” by Digital Persona. DB3 consists of fingerprints obtained using through thermal sweeping sensor “FingerChip FCD4B14CB” by Atmel and DB4 has synthetically generated fingerprints.

2.1. Multi-level Threshold Binarization:

Binarization is the process of converting a grayscale image into the binary image. There are different methods for binarizing, based on a local and global threshold. Multilevel Threshold technique involves clustering based image binarization and creates two clusters i.e. foreground and background so that the pixels fall in either foreground or background. Threshold value calculation is a critical step in this technique, which is done by calculating the histogram of each intensity value. Through binarizing, we get the binary map of ridges. Process is explained in the form of equation 1.

$$\sigma^2 = \sigma^2{}_w(t) + q_1(t)\,[1 - q_1(t)][\mu_1(t) - \mu_2(t)]^2 \qquad \text{------ (1)}$$

In equation 1, $\sigma^2{}_w(t)$ is within-class variance while $q_1(t)\,[1 - q_1(t)][\mu_1(t) - \mu_2(t)]^2$ is between-class variance.

2.2. Skeletonization:

In this structural operation, pixels from foreground are abraded away, leaving one-pixel wide ridge map. Skeletonization can be applied on both grayscale and binary images. Both techniques continue tracking the orientations and continuity of ridges and extract one-pixel wide skeleton of ridges.

2.3. Histogram Equalization:

Histogram equalization involves equalizing of intensity values of images so that they are mapped into new values by their adjustment. Histogram equalization causes contrast enhancement in an image and detail of ridges is increased.

2.4. Normalization:

Normalization is the process of adjusting gray level values, within the desired range of intensity values. Let I (i, j) represent the original gray-level value at pixel (i, j), and N (i, j) represent the normalized gray level value at pixel (i, j). The equation for normalizing a pixel is described in equation 2.

$$N(i,j) = \begin{cases} M_o + \sqrt{\frac{(V_o\, I(i,j) - M)^2}{V}} & \text{If } I(i,j) > M \\ M_o - \sqrt{\frac{(V_o\, I(i,j) - M)^2}{V}} & \text{else} \end{cases} \qquad \text{------------- (2)}$$

In equation 2, M and V represent the estimated value of mean and variance in the input image. While M_o and V_o represent the desired mean and variance values, respectively, so that gray-level values are normalized within this range.

2.5. Spatial Domain Filtering:

Spatial Domain filtering is a technique which modifies or enhances the image. It can be applied as pixel-wise operation and block wise operation both. Block size may also vary for different filters. Most common spatial domain filters in the field of fingerprint enhancement are the median filter and mean filter.

2.6. Frequency Domain Filtering:

This technique applies filtering on an image in its frequency domain. It is computationally less expensive than spatial domain filtering. The image is transformed using Fourier transformation and after this filtering is applied. After filtering, the image is retransformed into the spatial domain. Commonly used frequency domain filter for fingerprint enhancement is high-pass filtering which enhances high-frequency areas which are ridges.

The method proposed in this paper is a combination of some of the techniques described in the previous section. Figure 3 illustrates the steps of the method proposed here. In the first step, input fingerprint image is normalized by adjusting gray level values, within the desired range of intensity values. To achieve this, equation 2 is used. First mean and variance of the input image are calculated. Desired range of mean and variance is set to M_o=100 and V_o=150. Normalization does not add any additional information in the ridges. It is a pixel-wise operation and each pixel value is just re-adjusted.

After normalization of a fingerprint, Gabor filtering is applied on an image in the second step. Gabor filter is constructed by two necessary parameters (i) Ridge Orientation and (ii) Ridge Frequency. Gabor filter is applied block-wise, with a block size of 11 x11 pixels. In our technique, Gabor filter is tuned at ridge frequency of 60 cycles per image width while orientations used in the construction of the filter are 0^o to 157.5^o with a gap of 22.5^o. The general form of a Gabor filter is described in equation 3.

$$h(x, y: \theta, f) = e^{\left\{-\frac{1}{2}\left[\frac{(x\cos\theta)^2}{\delta x^2}+\frac{(y\sin\theta)^2}{\delta y^2}\right]\right\}\cos(2\pi f x\ \cos\theta)} \quad \text{---------} \ (3)$$

In equation 3, θ represents the orientation at which Gabor filter should be tuned to obtain ridge structure, f represents the frequency value while δx and δy represent the Gaussian kernel constants along x and y-direction, respectively. Eight Gabor filters with orientations mentioned above are applied on an image and a final convolved image is obtained in which structure of ridges is enhanced.

Image obtained from Gabor filtering is binarized in the third step. For the conversion of the gray scale fingerprint image to binary image, a multilevel threshold technique is used. A binary image contains only binary data so it is easy to differentiate ridges and valleys so that ridge structure is obtained. To achieve this, Otsu binarization is applied (Otsu, 1975). Foreground and background weights are calculated and variance within these classes are identified. On basis of these calculations, clusters of foreground and background are generated.

For the purpose of skeletonization, technique proposed by Zhang *et al.*. 1984 is used (Zhang and Suen, 1984). It involves two sub-iterations. Extraction of minutiae points in one-pixel wide ridge map is very easy and these points are further used for identification of fingerprint through an automated system.

3. Results and Discussion:

The purpose of the technique proposed here is to enhance a fingerprint for more suitable and reliable extraction of minutiae. An enhancement algorithm can be evaluated on the basis of a number of minutiae points extracted from a fingerprint, which is enhanced through that algorithm. That can be done both visually and quantitatively. Figure 4. (a-e) shows the process of enhancement on a fingerprint from DB2.

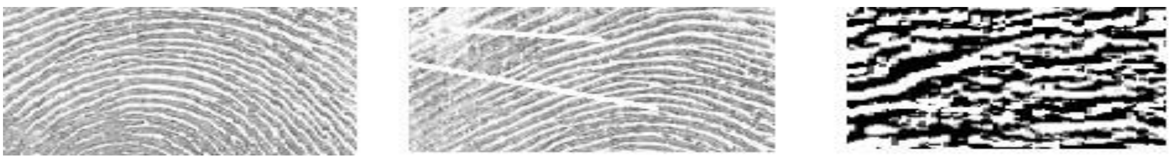
(a) Ridge Ending (b) Bifurcation

Figure 1: Structure of Ridge ending and Bifurcation

The overall result shows that with enhancement, 60% fingerprint images had minutiae in the standard range 40-100 (Hong *et al.*, 1998). Without enhancement, the score was 43%. These results were computed through goodness index (GI) (Ratha *et al.*, 1995). GI is defined in equation 4.

$$GI = \frac{\sum_{i=1}^{r} q_i\,[p_i - a_i - b_i]}{\sum_{i=1}^{r} q_i\,t_i} \qquad \text{-------- (4)}$$

In the above equation, r represents the number of 16x16 windows in the fingerprint image. p_i represents a number of paired minutiae in *the ith* window. q_i represents a quality factor in the *ith* window. Values for q_i are good=4, medium=2, poor=1. a_i represents a number of correct minutiae being missed in an *ith* window while b_i represents false minutiae identified.



(a) Well defined Region (b) Recoverable Region (c) Unrecoverable Region

Figure 2: Regions in fingerprint images

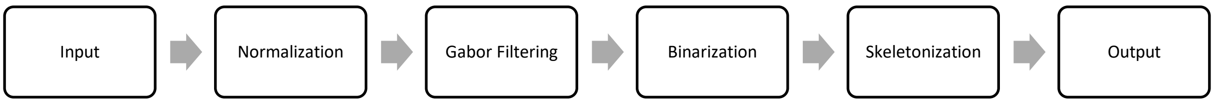


Figure 3: Steps of proposed method

In table 1, the GI value represents the mean of GI values of individual images in each database which is actually calculated by equation 5.

$$mean\ of\ GI = \frac{\sum_{i=1}^{n} GI_i}{n} \qquad \text{-------- (5)}$$

Here n represents the number of images in a database. GI_i represents the value of GI of *an ith* image. The wall time of this algorithm (in seconds) on a 3.0 GHz Pentium processor is described in Table 2. It takes total 0.13 sec to enhance a fingerprint image, which is efficient enough for a fingerprint identification system compared to the technique proposed by Hong *et al.* 1998 which has wall time value of 2.49 sec for 200 MHz processor. For 3.0 GHz it will take 0.16 sec (Hong *et al.*, 1998).

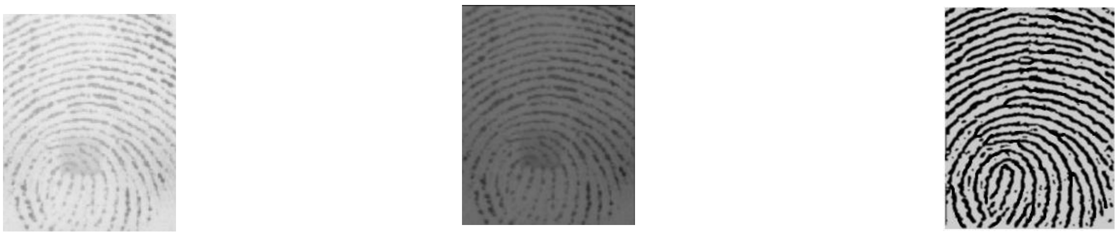
Table 1: Goodness index of AECFI algorithm

Databases (FVC 2004)	Without Enhancement(GI) (mean of the whole database)	With Enhancement (GI) (mean of the whole database)
DB1	0.55	0.61
DB2	0.39	0.57
DB3	0.51	0.65
DB4	0.27	0.39
	Overall Rate = 43%	Overall Rate = 60 %

The technique proposed in this paper enhances the quality of fingerprint images and clarify the structure of ridges using eight different orientations Gabor filters. For further enhancement Multi-level threshold Binarization is applied so that ridges and valleys are differentiated. Ridges obtained are further skeletonized so that a ridge is only one pixel wide and extraction of minutiae is done easily. The quality of an automated system for fingerprint identification relies on extraction and matching of minutiae. The purpose of this technique was enhancing the quality of poor quality images for reliable extraction of minutiae points. The proposed method can be used as a preprocessing step for minutiae extraction. The overall algorithm has effective and efficient results.

Table 2: Wall time of AECFI algorithm

Normalization	Gabor Filtering	Binarization	Skeletonization	Total
0.02 sec	0.08 sec	0.01 sec	0.02 sec	0.13 sec



(a) Compromised Fingerprint (b) Normalized Fingerprint (c) Gabor Filtering

(d) Binarized Fingerprint (e) Skeletonized Fingerprint

Figure 4: (a) original compromised fingerprint (b) normalization applied on the original image (c) the result after application of 8 Gabor filters. (d) The result of Multi-threshold Binarization (e) the result of fingerprint skeleton obtained through skeletonization.

Conflict of Interest:

Authors have no conflict of interest.

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