FINGERPRINT IMAGE ENHANCEMENT BASED ON THE GABOR FILTER

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ABSTRACT

Fingerprints were one of the first forms of biometric authentication to be used for law enforcement and civilian applications. Contrary to popular belief, despite decades of research in fingerprints, reliable fingerprint recognition is an open problem. Extracting features out of poor quality prints is the most challenging problem faced in this area. So it is essential to enhance the prints prior to feature extraction. This paper proposes an approach for fingerprint image enhancement based on the Gabor Filter. Ridge orientation, one of the important parameters of the filter, is estimated using the Sobel operator. But, the estimation of ridge frequency, which is another important parameter, is eliminated by giving a fixed value that leads to a fast enhancement process.

1. INTRODUCTION

As the fingerprint of an individual is unique and remains unchanged over a lifetime, it is the first biometric system adopted by law enforcement agencies, and now is also the most widely used system [8]. A fingerprint is formed from an impression of the pattern of ridges on a finger. A ridge is defined as a single curved segment, and a valley is the region between two adjacent ridges. The minutiae, which are the local discontinuities in the ridge flow pattern, provide the features that are used for identification. Details such as the type, orientation, and location of minutiae are taken into account when performing minutiae extraction [2].

Fingerprint image quality is of much importance to achieve high performance in Automatic Fingerprint Identification System (AFIS). Fingerprint images are rarely of perfect quality. They may be degraded and corrupted with elements of noise due to many factors including variations in skin and impression conditions. This 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 [13].

Enhancement of fingerprint images can be performed on either binary ridge images or direct grey images. Binarization before enhancement will generate more spurious minutiae structures and lose some valuable original fingerprint information. It also poses more difficulties for later enhancement procedure. Therefore, most enhancement algorithms are performed on grey images directly [15].

In this paper, Gabor filter based grey level fingerprint image enhancement approach is proposed. Section 2 presents other related enhancement systems. Background theory on the enhancement process can be seen in Section 3.System implementation is described in Section 4, which is followed by Section 5 in which the experimental results are discussed. The conclusion on the system performance, limitation of the system and further extension to the system are presented in Section 6.

2. LITERATURE REVIEW

Although several researches have proposed some enhancement techniques to this end, there is still scope for improvement. One of the most widely cited fingerprint enhancement techniques is the method employed by Hong et al. which is based on the convolution of the image with Gabor filters tuned to the local ridge orientation and ridge frequency. The main stages of this algorithm include normalization, ridge orientation estimation, ridge frequency estimation and filtering [11].

Greenberg has improved Hong's algorithm by using a unique anisotropic filter, which utilized only orientation information instead of both local ridge orientation and local frequency information [14].

Yang modified Hong's method by discarding the inaccurate prior sinusoidal plane wave assumption. The single period of frequency domain in Hong's method is substituted by two different frequencies, which best reflects the texture features of fingerprint image [10]. Fingerprint enhancement methods based on the Gabor filter have been widely used to facilitate various fingerprint applications such as fingerprint matching and fingerprint classification [4] [3].

Other alternative approaches [1] [12] [7] were also used for enhancement process but only the Gabor filter based approach increases the contrast between the foreground ridges and the background, whilst effectively reducing noise.

Hence, in this thesis, the Gabor filtering approach is chosen to perform fingerprint image enhancement.

3. BACKGROUND THEORY

The overview of the proposed system can be seen in figure 3.1.

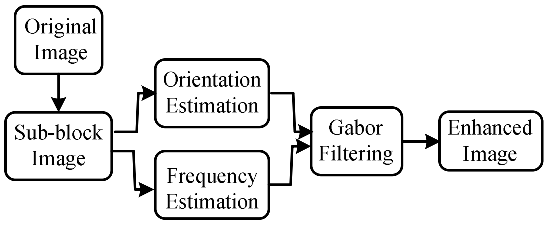

Figure 3.1. Gabor filter process diagram.

The methodology for each stage of the proposed enhancement approach will be discussed in the following sections. In each section, alternative approaches for each stage are reviewed firstly, and are followed by the proposed approach.

3.1. Ridge Orientation Determination

It is a fundamental step in the enhancement process to effectively enhance the fingerprint image. It can be accomplished using gradient-based approach [5], or model-based approach [6]. In this paper, the Sobel operator is used to compute the gradients. Then, the ridge orientation is determined using the following equation.

$$\theta = \tan^{-1} [(2*\sum dx\ dy) / (\sum dx^2 - \sum dy^2)], \quad (1)$$

where dx and dy are Gradient magnitudes in the x and y directions which are computed using the Sobel operator.

The horizontal Sobel mask used to compute dx is

$$\begin{bmatrix} \mathbf{1} & \mathbf{0} & \mathbf{-1} \\ \mathbf{2} & \mathbf{0} & \mathbf{-2} \\ \mathbf{1} & \mathbf{0} & \mathbf{-1} \end{bmatrix}$$

The vertical Sobel mask used to compute dy is

$$\begin{bmatrix} \mathbf{1} & \mathbf{2} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{-2} & \mathbf{-1} \end{bmatrix}$$

An example of the orientation image can be seen in figure 3.2.

(a) (b)

Figure 3.2. (a)Original image; (b)Orientation image.

3.2. Ridge Frequency

The ridge frequency is another intrinsic property of the fingerprint image. It is also a slowly varying property and hence is computed only once for each non-overlapping block of the image. It is estimated based on the projection sum taken along a line oriented orthogonal to the ridges [11], or based on the variation of gray levels in a window oriented orthogonal to the ridge flow [9]. But in some literatures, it is usually assumed that the ridge frequency to be constant across population and spatially uniform in the same finger [1].

So, in this paper, a commonly used value of 1/8 is given to the ridge frequency.

3.3. Gabor Filtering

Once the ridge orientation and ridge frequency information has been determined, these parameters are used to construct the even-symmetric Gabor filter.

Gabor filters are bandpass filters that have both frequency-selective and orientation-selective properties. These properties allow the filter to be tuned to give maximal response to ridges at a specific orientation and frequency in the fingerprint image. Therefore, a properly tuned Gabor filter can be used to effectively preserve the ridge structures while reducing noise.

The even-symmetric Gabor filter is the real part of the Gabor function, which is given by a cosine wave modulated by a Gaussian, Figure 3.3. An even-symmetric Gabor filter in the spatial domain is defined as:

$$G(x, y; \theta, f) = \exp\{-1/2[(x_\theta^2/\sigma_x^2) + (y_\theta^2/\sigma_y^2)]\} \cos(2\pi f x_\theta) \quad (2)$$

where

$$x_\theta = x\cos\theta + y\sin\theta, \quad (3)$$

$$y_\theta = -x\sin\theta + y\cos\theta, \quad (4)$$

where θ is the orientation of the Gabor filter, f is the frequency of the cosine wave, σ_x and σ_y are the standard deviations of the Gaussian envelope along the x and y axes, respectively, and x_θ and y_θ define the x and y axes of the filter coordinate frame, respectively.

Since the bandwidth of the filter is tuned to match the local ridge frequency, then it can be deduced that the parameter selection of σ_x and σ_y should be related with the ridge frequency. However, in the original algorithm by Hong et al., σ_x and σ_y were empirically set to fixed values [11].

In this proposed approach, σ_x and σ_y are also given to fixed values of 4.9 and 4.9, respectively.

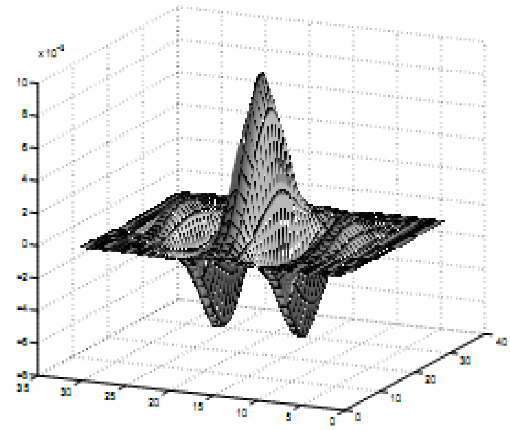

Figure 3.3. An even-symmetric Gabor filter in the spatial domain.

4. SYSTEM IMPLEMENTATION

The overall system design of fingerprint image enhancement system is described with system flow diagram in Figure 4.1.

4.1. Proposed System Design

In Figure 4.1, the system firstly acquires the scanned images or downloaded images (from NIST) as the input. The system can accept grey level image of any format such as tif, jpg, bmp etc. Then, the input image is divided into sub- blocks of size 10x10. The next step is to decide if the noise is added or not. If it is desired to add the noise, choose the noise type: salt & pepper, or gaussian, or poisson. Otherwise, it is needed to decide if the Gabor filter is used. If yes, ridge orientation has to be estimated first. This step is followed by Gabor filtering process which results in an enhanced image. The final process is histogram equalization of the enhanced image. If it is not desired to filter with the Gabor filter but with the other filter, the filter type must be chosen: median, or mean, or gaussian.

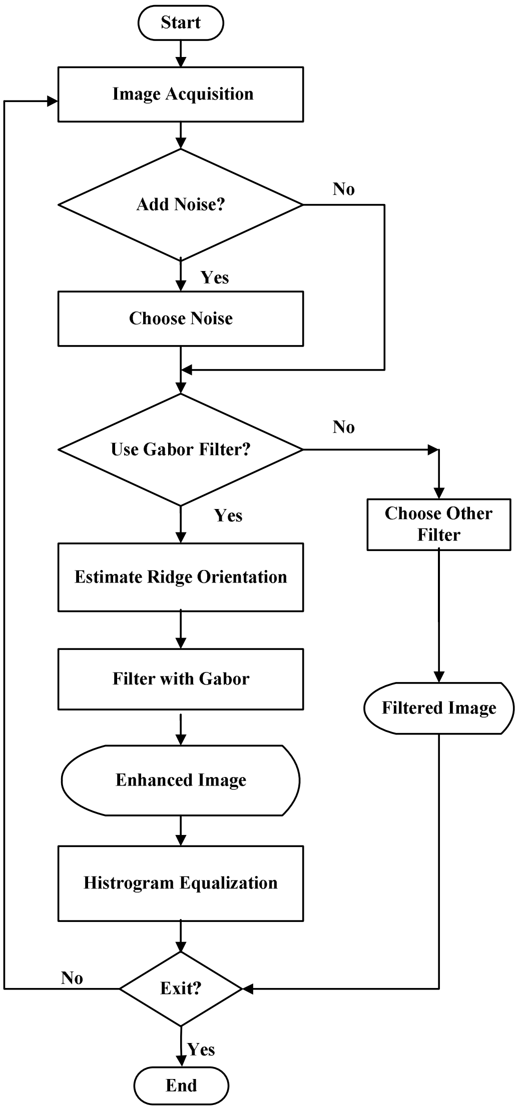

Figure 4.1. Design of the system

4.2. Experimental Results

Experiments were carried out on Pentium IV of 1.60GHz, 512MB memory, by using gray-scale fingerprint images. Several experiments were carried out to get optimum information for the proposed approach so that the system is effective. Input images of various sizes were filtered with different mask sizes. Among the resulted images, some can be seen as in Figure 4.2, 4.3, and 4.4, where the input image is Figure 3.2 (a).

(a) (b) (c)

Figure 4.2. Enhanced image resulted by input image of size (a) 150*150; (b) 250*250; (c) 300*300; with mask size of 10.

(a) (b) (c)

Figure 4.3. Enhanced image resulted by input image of size (a) 150*150; (b) 250*250; (c) 300*300; with mask size of 16.

(a) (b) (c)

Figure 4.4. Enhanced image resulted by input image of size (a) 150*150; (b) 250*250; (c) 300*300; with mask size of 32.

(a) (b) (c)

(d) (e)

Figure 4.5. Resulted image of (a) original image; filtered with (b) Gabor filter; (c) Median filter; (d) Mean filter; and (e) Gaussian filter.

5. DISCUSSION ON THE EXPERIMENTAL RESULTS

According to the experimental results shown in Table 1, input image of size 250*250 with mask size of 10 can offer the best quality enhanced image. It only takes about half a minute for enhancement process. Experimental results show that the larger the mask size, the longer time the system takes to enhance the image. Since, commercially available fingerprint readers use images of size 250*250 as the input, the system will be more effective with this image size.

Moreover, it can clearly be seen from Figure 4.5 that apart from the Gabor filter, the other filters are unable to enhance the fingerprint image, but are able to reduce noise only. On the other hand, the Gabor filter can not only remove noise but can also enhance the input image. That is why the Gabor filter is widely used in enhancement process.

Table 5.1. Experimental Results

Size of the input image	Mask Size	Time(seconds)
150*150	10	10.7954
	16	20.8709
	32	27.4345
250*250	10	34.9465
	16	70.7054
	32	164.129
300*300	10	52.1111
	16	109.7066
	32	331.2595

6. CONCLUSION AND FURTHER EXTENSION

This paper primarily focuses on the enhancement of fingerprint images, which is essential for the subsequent processes of matching and recognition. Enhanced images show that the filter preserves the continuity of the ridge flow pattern and enhances the clarity of the ridge and valley structures. In addition to reducing noise in the image, the filter is able to fill in small breaks that occur within ridges. So the proposed system can reduce false minutiae points. It can clearly be seen that the resulted images are acceptable for further processes of matching and recognition. Moreover, using a constant value for the ridge frequency leads to a fast enhancement process. The system is simple but effective.

The system can be extended as a recognition system by using other faster filtering techniques to effectively reduce the time taken for filtering process.

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