Efficient Enhancement Algorithm Based on Local Properties for Fingerprint Images

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ABSTRACT
In this paper, an improved algorithm for enhancement of fingerprint images is proposed on the basis of image normalization and the Gabor filter. The adaptive normalization based on block processing is suggested for improvement of fingerprint images. An input image is partitioned into sub-blocks with the size of $K \times L$ at first and the region of interest (ROI) of the fingerprint image is acquired. The parameters for the image normalization are adaptively determined according to the statistics of each block. By utilizing these parameters, the block image is normalized for the next process. A new technique for selection of two important parameters of the Gabor filter is devised. These parameters are the ridge direction and the ridge frequency. The ridge direction of a block image is determined by a probabilistic approach unlike other works. With this ridge direction, the ridge frequency is selected by utilizing the directional projection and its frequency response. The proposed algorithms are tested with the NIST fingerprint images and show significant improvement in the experiments.

KEY WORDS
Fingerprint, Adaptive Normalisation, Gabor Filter, Enhancement

1 Introduction

Fingerprints are today the most widely used biometric features for personal verification. Most automatic fingerprint verification systems are based on minutiae pattern matching [1]-[6]. Minutiae are the local discontinuities, in the fingerprint pattern, which represent terminations and bifurcations.

To obtain the minutiae from a given fingerprint image which is captured from a directly scanning sensor or digitization of an inked fingerprint, a ridge structure should be extracted at first. As the quality of the acquired images, the ridge structures in the fingerprint images are not always well defined. Therefore, some enhancement processes as preprocessing are necessary to get more reliable feature extraction.

Many kinds of enhancement methods for fingerprint images have been proposed in the literatures [1]-[7]. Most of them are based on image binarization, while some others enhance images directly from gray scale images [1]-[6]. In the approach for the gray scale images, the enhancement algorithm includes the following main steps [2] as shown in Fig. 1: 1) Normalization, 2) Local orientation estimation, 3) Local frequency estimation, and 4) Filtering by a bank of the designed filters.

In the normalization step, an input fingerprint image is normalized to decrease the dynamic range of the gray scale between ridges and valleys of the image in order to facilitate the processing of the following steps. And the orientation image is estimated from the normalized fingerprint image by employing the gradient information. In the next step, the frequency image is computed from the normalized image and the estimated orientation image. A bank of pre-tuned filters is applied to the ridge and valley pixels in the normalized fingerprint image to obtain an enhanced fingerprint image in the last step. In general, the Gabor filter is employed for enhancement of the fingerprint image.

![Block diagram of fingerprint image enhancement](image.png)

Figure 1. Block diagram of fingerprint image enhancement

In this paper, we suggest a new method for selection of two important parameters of Gabor filter for enhancement of the fingerprint image. To get the enhanced fingerprint image, the original input image is partitioned into sub-blocks with the size of $K \times L$ and normalized with the local properties for the next process. Unlike other works which employed the average method of the gradient image, we devise a probabilistic approach for determination of the ridge direction. Also, the ridge frequency is obtained
by employing the directional projection with the acquired ridge direction.

This paper is organized as follows. In Section 2, the adaptive image normalization, which is based on the block processing, is explained in brief. Also, a new method for selection of two important parameters of the Gabor filter is proposed in Section 2. For performance validation of the proposed algorithm, the proposed algorithm is tested with the NIST fingerprint images in Section 3. Finally, we will draw a conclusion for this work in Section 4.

2 The Proposed Algorithm for Enhancement of Fingerprint Images

2.1 Adaptive Image Normalization Based on Local Properties

The input fingerprint images which are obtained from sensors may have imperfections or poor quality due to non-uniformity of ink intensity or non-uniform contact with the sensor by users. To cope with this problem, an adaptive normalization algorithm based on the local properties of the given fingerprint image is proposed. For a given fingerprint image $I$ which is defined as an $N \times M$ matrix and $I(i, j)$ represents the intensity of the pixel at the $i$-th row and $j$-th column, Hong and Jain have employed the following normalization processing [2]:

$$
G(i, j) = \begin{cases} 
M_0 + \frac{VAR_0 (I(i, j) - M)^2}{VAR}, & I(i, j) > M, \\
M_0 - \frac{VAR_0 (I(i, j) - M)^2}{VAR}, & \text{otherwise,}
\end{cases}
$$

(1)

where $M_0$ and $VAR_0$ are the desired mean and variance values, $M$ and $VAR$ are the computed mean and variance of the given image.

For the estimated initial $M_0^d$ and $VAR_0^d$, $M_0^d$ and $VAR_0^d$ are varied to adapt for the local properties of the current block. Let $M_0^d$ and $VAR_0^d$ be the desired parameters for normalization of the $i$-th block in the fingerprint image, the updating equations are written as following:

$$
M_i^d = M_0^d + \alpha_1 \cdot (M_i - M_0^d),
$$

(2)

$$
VAR_i^d = VAR_0^d + \alpha_2 \cdot (VAR_i - VAR_0^d),
$$

(3)

where $\alpha_1$ and $\alpha_2$ are weighting factors which represent the degree of contribution of the variation term, $M_i$ and $VAR_i$ are the computed mean and variance of the $i$-th block, respectively.

The second terms in the right-hand side of the above equations are the variations which are considered as the local properties of the $i$-th block. As these terms contribute to the desired parameters, the desired parameters are changed according to the local properties of the current block.

Figure 2 shows the result of the adaptive image normalization based on block processing.

![Figure 2. Result for the image normalization of NIST-605: (a) Original image, (b) Adaptive normalization based on block processing](image)

2.2 Automatic Selection of Parameters for the Gabor Filter

After the normalization process for fingerprint images, the filtering process is executed by employing some filters. The Gabor filter is usually used to enhance the normalized images [2]. The Gabor filter for enhancement of fingerprint images can be written as following:

$$
h(x, y; \theta, f) = \exp\left(-\frac{1}{2} \left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right)\right) \cos(2\pi f x \theta)
$$

(4)

where $\theta$ is the orientation of the Gabor filter, $f$ is the frequency, $\sigma_x$ and $\sigma_y$ are the space constants of the Gaussian envelope along $x$ and $y$ axes, respectively.

To make use of the Gabor filter, two important parameters must be tuned. These are $\theta$ and $f$ in Eq. (4). This study proposes an automatic selection technique of $\theta$ and $f$ for the Gabor filter.

2.2.1 Selection of Ridge Direction $\theta$

Most methods, which utilize the ridge direction to design a filter, use the minimum square adjustment algorithm or the gradient-based averaging algorithm [1, 2] to implement easily. Since, however, these algorithms are sensitive to noise. Thus, we try to make use of a probabilistic approach in this study.

Firstly, a gradient image is generated to compute the angle of the ridge at each pixel. For a probabilistic approach to obtain the ridge direction, the range of angle of the ridge is given as $[-90^0 \sim +90^0]$. In this range, the angle is quantized by an equi-interval $q$ to compute the distribution of the angle or direction of the ridge.

Then, the distribution of the direction of the ridge is generated by the nearest neighbor level concept as following:

$$
\text{Arg} \min_{\theta_i \in \{-90^0, -90^0 + q, -90^0 + 2q, \ldots, +90^0\}} |\theta_i - \ell|,
$$

(5)

where $\theta_i$ is the computed angle at $i$-th pixel.

For example, if $\theta_i$ is the nearest to the angle level
\(-90^\circ + n\theta, \) then the frequency of the angle level \(-90^\circ + n\theta\)
increases by unit one. In this research, the quantization level is set to \(q = 2^\theta.\) By using the constructed distribution
of the angle \(p(\theta_i),\) the best direction of the ridge can be selected by the maximum likelihood criterion as following:

\[
\theta^* = \text{Arg} \max_{\theta_i} \{p(\theta_i)\}. \tag{6}
\]

In the previous works, the corrupted angle components can affect the final estimation of the ridge direction. However, the proposed method for estimation of the ridge direction selects the dominant direction in the distribution of the angle. Therefore, some corrupted direction components do not influence the final estimation of the ridge direction.

2.2.2 Selection of Ridge Frequency \(f\)

For estimation of the ridge frequency, the estimated direction of the ridge is employed. Since the direction of the ridge is given in priori, the ridge image is projected onto the perpendicular axis of the given ridge direction. The projection data can provide the frequency of the ridge lines in the current block.

Figure 3 shows an example for the directional projection to estimate the frequency of the ridge. It can be seen that the waveform from the projection data can give the information of the ridge frequency. Since the acquired waveform has a sinusoidal form, we estimate the frequency of the ridge pattern for each block image by employing Fast Fourier Transform (FFT). In Fig. 3(c), the frequency of the ridge pattern can be automatically selected as the dominant frequency which has the maximum magnitude in the frequency domain (except DC component). In this example, \(f\) is chosen as 2.

3 Simulation Results

To verify the proposed algorithm, we have used fingerprint images from the database of the NIST Fingerprint Image Groups and Huno Magic Secure 2000. The NIST images derived from digitized inked fingerprints, each consisting of \(512 \times 480\) pixels, in 8-bits gray scale. For processing the block unit, the size of the partitioned block is selected as \(24 \times 24\) in this work.

Figure 2 presents the result when \(\alpha_1 = \alpha_2 = 0.5\) and \(M_0^d = 100\) and \(VAR_0^d = 50.\) As shown in Fig. 2(a), we can see that the fingerprint image is not uniform due to some causes. As shown in the result, the proposed algorithm that utilizes the block based processing can improve the original image by using the devised adaptive normalization method. This is due to consideration of the local properties.

Figure 4 shows the estimation results of the ridge direction in the NIST fingerprint image. Although the noisy clutter is attached to the true ridge, we can see that the proposed method gives subjectively better results in estimation.
of the ridge direction than the previous method.

To demonstrate the feasibility of the suggested algorithm, the NIST fingerprint images are tested on the proposed algorithm. Figure 5 illustrates the results of the enhancement with our method. Many parts of the given fingerprint image are complemented and improved in the results.

Finally, the enhanced fingerprint images are displayed in Fig. 6. As shown in the result, it can be known that the proposed enhancement algorithm with the designed Gabor filter produces very reliable results.

4 Conclusions

In this study, a new enhancement algorithm for fingerprint images is proposed by utilizing the adaptation for the properties of the local regions and the automatic selection of parameters for the Gabor filter. By taking the local properties into account, the adaptive normalization process could ensure the reliable fingerprint texture region of the given fingerprint image, although the image has poor quality.

To obtain the final enhanced image by employing the Gabor filter, the automatic selection technique for two important parameters of the filter is devised. As shown in the experiments, the proposed algorithms are very useful for enhancing the fingerprint images.

References


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Figure 6. Final results of fingerprint images: (left column)-The original images, (right column)-The enhanced images

Figure 7. Block scheme of fingerprint image enhancement