Research & Reviews (https://www.rroij.com/) International Journal of Innovative Research in Computer and Communication Engineering

ISSN ONLINE(2320-9801) PRINT (2320-9798)

Fingerprint Image Enhancement Algorithm and Performance Evaluation

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Abstract

Fingerprint identification is one of the most important biometric technologies which has drawn a substantial amount of attention recently. The uniqueness of a fingerprint is exclusively determined by the local ridge characteristics and their relationships. Very important. Fingerprint images get degraded and corrupted due to variations in skin and impression conditions. Thus, image enhancement techniques are employed prior to minutiae extraction. However, the performance of a minutiae extraction algorithm relies heavily on the quality of the input fingerprint images. Here introducing a fast fingerprint enhancement algorithm, which can adaptively improve the clarity of ridge and valley structures of fingerprint images based on the estimated local ridge orientation and frequency and evaluated the performance of the image enhancement algorithm using the goodness index of the extracted minutiae and the accuracy of an online fingerprint verification system.

Keywords

Biometric; Enhancement; Fingerprint; Minutiae; ridge; Performance

INTRODUCTION

A fingerprint is the pattern of ridges and valleys on the surface of a fingertip. Each individual has unique fingerprints. The uniqueness of a fingerprint is exclusively determined by the local ridge characteristics and their relationships [1] . A total of 150 different local ridge characteristics (islands, short ridges, enclosure, etc.) have been identified. These local ridge characteristics are not evenly distributed. Most of them depend heavily on the impression conditions and quality of fingerprints and are rarely observed in fingerprints. 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. The set of minutiae types are restricted into only two types, ridge endings and bifurcations. Ridge endings are the points where the ridge curve terminates, and bifurcations are where a ridge splits from a single path to two paths at a Y-junction. Figure 1.1 illustrates an example of a ridge ending and a bifurcation. In this example, the black pixels correspond to the ridges, and the white pixels correspond to the valleys.

A good quality fingerprint typically contains about 40–100 minutiae. The quality of fingerprint images should be reduced due to noise, skin conditions etc. So some Enhancement technique is needed for improving the quality of fingerprint.

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 neighbouring 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 neighbouring regions do not provide sufficient information about the true ridge and valley structures either.

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.

RELATED WORK

The ridge structures in poor-quality fingerprint images are not always well-defined and they cannot be correctly detected. This leads to following problems:

1) A significant number of spurious minutiae may be created.

2) A large percent of real minutiae may be ignored,

3) Large errors in their localization (position and orientation) may be introduced.

In order to ensure that the performance of the minutiae extraction algorithm will be robust with respect to the quality of input fingerprint images, an enhancement algorithm which can improve the clarity of the ridge structures is necessary. One of the most widely used fingerprint enhancement techniques is the method employed by Hong [2] , 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 normalisation, ridge orientation estimation, ridge frequency estimation and filtering.Sharat S. Chikkerur et al. [3] introduced an approach for fingerprint enhancement based on Short Time Fourier transform (STFT) Analysis algorithm proposed by them estimated all the intrinsic properties of fingerprints'. Greenberg et al. [4] Proposed two methods for image enhancement. One is using histogram equalization, Wiener filtering and image binarization and other is using anisotropic filter for direct gray scale enhancement .Tsai-Yang Jea et al. [5] presented an approach that use localized secondary features derived from relative minutiae information .D.K. Misra et al. [6] proposed a method for fingerprint enhancement in Fourier domain and matching based on minutiae matching.

FINGERPRINT ENHANCEMENT ALGORITHM

Fingerprint enhancement can be conducted on either

1) Binary images or

2) Gray level images.

A binary ridge image is an image where all the ridge pixels are assigned a value one and valley pixels are assigned a value zero. However, after applying a ridge extraction algorithm on the original gray-level images, information about the true ridge structures is often lost depending on the performance of the ridge extraction algorithm. Therefore, enhancement of binary ridge images has its inherent limitations. In a gray-level fingerprint image, ridges and valleys in a local neighbourhood form a sinusoidal-shaped plane wave which has a well-defined frequency and orientation. Fingerprint enhancement algorithm includes the following.

? Normalisation,

? Segmentation

? Orientation estimation,

? Ridge frequency estimation

? Gabor filtering.

? Binarization and Thinning

The flow diagram of fingerprint input image is as follows.

A. Normalization

An input fingerprint image is normalized so that it has a pre specified mean and variance. 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. Let I(i; j) represent the grey-level value at pixel (i; j), and N(i; j) represent the normalized grey-level value at pixel (i; j). The normalized image is defined as:

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

where M and V are the estimated mean and variance of I(i; j), and M0 and V0 are the desired mean and variance values, respectively. 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.

B. Segmentation:

Segmentation is the process of separating the foreground regions in the image from the background regions. The foreground regions correspond to the clear fingerprint area containing the ridges and valleys .The background corresponds to the regions outside the borders of the fingerprint area, which do not contain any valid information. When minutiae extraction algorithms are applied to the background regions of an image, it results in the extraction of noisy and false minutiae. In a fingerprint image, the background regions generally exhibit a very low grey-scale variance value, whereas the foreground regions have a very high variance. Hence, a method based on variance thresholding can be used to perform the segmentation.

A segmented view of fingerprint image is as shown in the figure. Firstly, the image is divided into blocks and the greyscale variance is calculated for each block in the image. If the variance is less than the global threshold, then the block is assigned to be a background region; otherwise, it is assigned to be part of the foreground.

C. Orientation Estimation:

The orientation field of a fingerprint image defines the local orientation of the ridges contained in the fingerprint. The orientation estimation is a fundamental step in the enhancement process as the Gabor filtering stage relies on the local orientation in order to enhance the fingerprint image. The least mean square (LMS) estimation method employed by Hong [2] et al. is used to compute the orientation image. The fig 3.3 represents orientation estimation.

D. Ridge frequency estimation and Gabor Filtering:

In addition to the orientation image, another important parameter that is used in the construction of the Gabor filter is the local ridge frequency. The frequency image represents the local frequency of the ridges in a fingerprint. The first step in the frequency estimation stage is to divide the image into blocks of size W * W. The next step is to project the grey-level values of all the pixels located inside each block along a direction orthogonal to the local ridge orientation. The following figure describes the Gabor filter operation in spatial domain.

Once the ridge orientation and ridge frequency information has been determined, these parameters are used to construct the even-symmetric Gabor filter. A two dimensional Gabor filter consists of a sinusoidal plane wave of a particular orientation and frequency, modulated by a Gaussian envelope. Gabor filters are employed because they have frequencyselective 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 for reducing noise.

E. Binarization and Thinning

Binarization is the process that converts a grey level image into a binary image. This improves the contrast between the ridges and valleys in a fingerprint image, and facilitates the extraction of minutiae. The binarization process involves examining the grey level value of each pixel in the enhanced image, and, if the value is greater than the global threshold, then the pixel value is set to a binary value one; otherwise, it is set to zero. Thinning is a morphological operation that successively erodes away the foreground pixels until they are one pixel wide. A standard thinning algorithm is employed, which performs the thinning operation using two sub iterations.

PERFORMANCE EVALUATION

A. Evaluation using Goodness Index

We used the goodness index (GI) of the extracted minutiae to quantitatively assess the performance of our fingerprint enhancement algorithm. The larger the value of GI, the better the minutiae extraction algorithm. The maximum value of GI equals one, which means there are no missing and spurious minutiae. Our fingerprint enhancement algorithm was tested on 50 typical poor fingerprint images.

Image #	Goodness Index (GI)	
	Without Enhancement	With Enhancement
1	0.46	0.55
2	0.38	0.52
3	0.29	0.42
4	0.26	0.39
5	0.21	0.35
6	0.12	0.31
7	0.11	0.26
8	0.10	0.29
mean	0.24	0.39
std	0.05	0.04

First, we computed the goodness index of the extracted minutiae without applying the enhancement algorithm and then the goodness index of the extracted minutiae was computed with the enhancement algorithm applied to the input fingerprint images before the minutiae were extracted. Table shows the GI values of eight typical fingerprint images and the mean and standard deviation of GI values for all the 50 images. The GI values after applying the enhancement algorithm are always larger than that without the enhancement algorithm. Thus, we can conclude that our fingerprint enhancement algorithm does improve the quality of the fingerprint images, which, inturn, improves the accuracy and reliability of the extracted minutiae.

B. Evaluation using Verification Performance:

The performance of the enhancement algorithm was also assessed on the first volume of the MSU fingerprint database (700 live-scan images; 10 per individual) using the verification accuracy of an online fingerprint verification system [6]. We demonstrated that incorporating the enhancement algorithm in the fingerprint verification system improves the system performance. In the first test, fingerprint image in the data set was directly matched against the other fingerprint images in the database. In the second test, the fingerprint enhancement algorithm was applied to each fingerprint image in the data set. Then, the verification was conducted on the enhanced fingerprint images.

From these experimental results, we can observe that the performance of the fingerprint verification system is significantly improved when our fingerprint enhancement algorithm is applied to the input fingerprint images.

CONCLUSION

A fast fingerprint enhancement algorithm which can adaptively improve the clarity of ridge and valley structures based on the local ridge orientation and ridge frequency estimated from the inputted image is introduced. The performance of the algorithm was evaluated using the goodness index of the extracted minutiae and the performance of an online fingerprint verification system which incorporates our fingerprint enhancement algorithm in its minutiae extraction module. Experimental results show that our enhancement algorithm is capable of improving both the goodness index and the verification performance

Figures at a glance

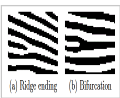

Figure 1

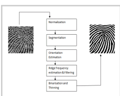

Figure 2

Figure 3

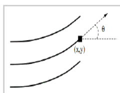

Figure 4

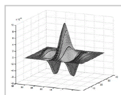

Figure 5

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