Block Based Low Quality Fingerprint Image Enhancement

NEBOJSA MARTINOVIC
John Naisbitt University
Graduate School of Comp. Sci.
Bul. umetnosti 29, Belgrade
SERBIA
macaniste@yahoo.com

MARKO BEKO
Univ. Lusófona de Humanidades e Tecnologias
Computer Engineering Department
Campo Grande 376, 1749 - 024, Lisbon
PORTUGAL
marko@isr.ist.utl.pt

MILAN TUBA *
John Naisbitt University
Graduate School of Comp. Sci.
Bul. umetnosti 29, Belgrade
SERBIA
tuba@ieee.org

Abstract: Quality of the fingerprint images is important for the proper performance of the fingerprint image matching algorithm and recognition by fingerprint recognition systems. In this work we proposed modified fingerprint enhancement image normalization by taking into consideration properties of local region. For testing purposes, we used fingerprint images from NIST database and images were divided into sub-blocks (A x B). Our results confirmed considerable fingerprint image enhancement when proposed algorithm was applied. The achieved enhancement was validated by the number of extracted minutiae.

Key–Words: Fingerprint recognition, fingerprint minutiae, recognition system, image processing

1 Introduction

Fingerprint recognition is the most widely used biometric measure and also the biometric feature with the largest databases. Personal identification by fingerprint is used for more than decades and was shown as method with best long-term widely experience. Increasing demands for automated personal authentication in terms of physical access control and digital signature creation, use of fingerprint was particularly emphasized [1]. The fingerprint is unique pattern of friction ridges on a human finger. Fingerprint is individual characteristic, remain unchanged during a lifetime and has general ridge patterns that makes it suitable to be classified [2]. The uniqueness of a fingerprint is determined by the local ridge characteristics and their positions [3]. A ridge is defined as a single curved segment, and a valley is the region between two adjacent ridges.

Also, each ridge contains pores, which are attached to sweat glands under the skin. Fingerprints are left on smooth surfaces like glass or paper, because of this sweat. The ridges of fingerprints have been classified to form three patterns called loops, whorls and arches. A loop begins on one side of the finger, curves around or upward, and exits from the other side. There are two types of loops: radial loops which slope toward the thumb and ulnar loops which slope towards the little finger. Whorls form a circular or spiral pattern. Arches slope upward and then down, like very narrow mountains. The minutiae, the local discontinuities in the ridge flow pattern, are small details that can determine important local features in the fingerprint image. There are two types of minutiae, ridge endings and ridge bifurcations. A ridge ending indicates the location where a ridge curve terminates and bifurcations are where a ridge breaks up into two ridges. Considering that fingerprint analysis is a effective as a means for identification, many automatic fingerprint recognition approaches have been suggested. For determination of the accuracy of automatic fingerprint recognition system a computerized system called automated fingerprint identification system (AFIS) was developed [4]. This system use complex algorithms and it is able to sift through huge number of fingerprints and to compare them in short period of time. This system and its data base is very effective in cases where there are no particular suspected matches. It is of the utmost importance that fingerprint images are taken properly because smudged or not fully rolled from nail-to-nail fingerprints could cause "false" minutiae on the image which could alter the search results. It is critical that each minutiae marker is accurately set to increase the chances of a match. Obtaining adequate impressions on fingerprint cards could be achieved through continued practice and use of right equipment.

Quality of the fingerprint images is important for the proper performance of the fingerprint image matching algorithm. The more high-quality samples are the fingerprint recognition systems are more accurate. A fingerprints with distinguishable patterns

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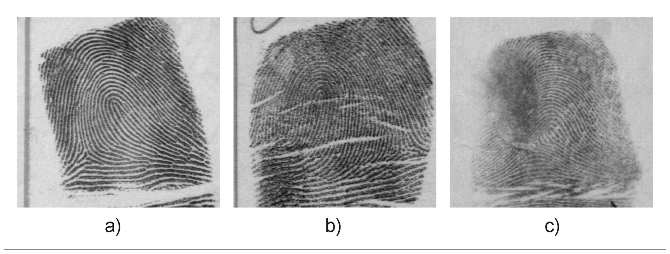

Figure 1: a) A good quality fingerprint image; b) Fingerprint with scars and ridge breaks; c) Low quality fingerprint image with a lot of noise

and features that can be extracted and, subsequently, used for matching are generally considered to be a good quality. Local ridge characteristics are not evenly distributed and the quality of fingerprint images can be affected by user's skin condition, improper finger placement, scanner limitation or impurities on the scanner surface. In practice, a significant number of fingerprint images is of poor quality and that result in spurious and missing features (Fig. 1). A good quality fingerprint typically contains about 40-100 minutiae. For a fingerprint image of low quality, a large number of false minutiae may be extracted. Therefore, after careful fingerprint image quality assessment, fingerprint image enhancement is very important and required step after image acquisition and before feature extraction in the fingerprint recognition system [5].

A biometric system has three phases: biometric data acquisition, feature extraction and decision-making. The acquisition phase is very important and highly depends on image quality. If quality of images is not appropriate, the feature extraction phase cannot operate reliably. This rest of this paper is organized as follows. Section 2 is about the literature review. Details of the our proposed fingerprint enhancement algorithm are given in Section 3. Experimental results are given in Section 4. Section 5 concludes the paper and discusses the perspectives.

2 Literature Review

Based on whether the filter kernel is orientation sensitive, filtering techniques can be divided into two broader categories: isotropic and anisotropic filtering. The most commonly used isotropic filters are Gaussian filter [6] and median filter [7]. The main disadvantage of these filters is the inability to enhance a fingerprint image considering that fingerprint is non-stationary and ridge size, orientation and length varies from part to part. Anisotropic filtering can effectively remove noises from the image but reliable orientation must be provided. Therefore, in several studies, investigators have attempted to find the best possible image enhancement algorithm.

Traditional Gabor filters optimally capture both local orientation and frequency-selective properties of fingerprint image. In order to enhance fingerprint image, number of researchers had applied Gabor filters to enhance flow-like patterns. One of the examples was proposed by Hong and al. in [8]. Gabor filter banks were used to enhance fingerprint images based on the estimated local ridge orientation and frequency and reported solid improvement of the clarity. There are five stages of this algorithm: normalization, ridge orientation estimation, ridge frequency estimation, filtering and thinning. In [9] a algorithm for automatic fingerprint recognition in two stages was proposed. In the first one, biometric characteristics of fingerprints are extracted and in the second stage, those fingerprints are matched with templates belonging to the test database.

In [10] enhance of fingerprint images was done by combining the Gabor filter and FFT. Proposed method for fingerprint image segmentation was based on the image histogram and density. Enhances was done by using the better enhancing filter in each part and the experimental results showed that this combination provide good enhancement.

Similiar method as in [10] was proposed in [11]. For fingerprint image enhancement instead of combination of Gabor filter and FFT, FFT was applied on 32×32 and Gaussian filter was used in each interconnection of the blocks.

In [12] two methods for fingerprint image enhancement were introduced. One was using histogram equalization, Wiener filtering and image binarization while the other was using anisotropic filter for direct gray scale enhancement. In [13] an improved version called modified Gabor filter was introduced. It was shown that modified Gabor filter can significantly reduce the false rejection rate.

Considering that clarity of the images and the degree of correspondence between the search print and the database print is critical for fingerprint matching, there are several methods proposed to overcome low quality images of fingerprints that come from degraded and corrupted with elements of noise. In order to remove scars, in [14]. the diffusion matrix was proposed to reconstruct the broken ridges. An estimation of the flow of ridges and valleys by line sensor was presented in [15]. A directional filter that strengthens the ridge pattern of local dominant orientation and suppress scar lines that are oriented against the dominant direction was used in [16] to reconstruct the patterns in acquired images. In [17] a technique that employs contrast stretching approach to improve the clarity between foreground and background of the fingerprint image was proposed.

In [18] a method for fingerprint enhancement based on orientation field estimation algorithm was proposed. Orientation was determined by prior knowledge of fingerprint structure. A dictionary of reference orientation patches was used for representing the orientation. Loopy belief propagation was used for estimation of orientation field which was posed as an energy minimization problem.

Keun et al. [19] proposed the algorithm that decomposes a fingerprint image in the analysis stage, processes parts in the processing stage and put them back together as the enhanced image in the synthesis stage. This improved algorithm reduces the influence of noise on the ridges and valleys, enhances the ridges moving shape and preserves the spatial characteristics at minutiae and singular points.

In [20] an approach for fingerprint enhancement that estimate all the intrinsic properties of fingerprints was introduced. In [21] fingerprint image enhancement using decimation-free directional filter bank which provides output in the form of directional images was employed. These algorithms are useful for good quality images but in case of low quality images their performance decrease due to the noise such as smudges, imperfections, crevasses and holes, so these images enhancement is worth of investigation.

In [22] spectral filtering was proposed as algorithm for fingerprint enhancement. Adaptive boost spectral filtering algorithm was based on a progressive enhancement with additional feedback in a spatial-partitioning and frequency-domain approach. Gaussian-matched filter was applied and it started from high-quality regions and finished to lower-quality regions by iterating though a good spectra of enhanced ridges.

3 Fingerprint Enhancement Algorithm

Fingerprint enhancement can be conducted on binary images or 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 neighborhood form a sinusoidal-shaped plane wave which has a well defined frequency and orientation.

Fingerprint enhancement algorithm includes several techniques. All these steps in figure enhancement are very important before fingerprint image is introduced to fingerprint recognition systems. These techniques are:

- Normalization
- Segmentation
- Orientation estimation
- Ridge frequency estimation
- Gabor filtering
- Binarization and thinning

In order to standardize pixel intensity, normalization should be the first process step in image enhancement process. This can be done by adjusting the range of gray level to a previously determined mean value and variance value. Every image has finite number of rows and columns, rows are represented as i, and columns are represented as j in a (i, j) matrices. We can state that intensity $I(i, j)$ represent the grey-level value at pixel (i, j), and $N(i, j)$ represent the normalized grey level value [7]. The normalized image can be defined as:

$$G(i,j) = \begin{cases} Mo + \sqrt{(VARo(I(i,j) - M)^2/VAR} \\ \quad if\ I(i,j) > M, \\ \\ Mo - \sqrt{(VARo(I(i,j) - M)^2/VAR} \\ \quad otherwise \end{cases} \quad (1)$$

(2)

where M and V are the estimated mean value and variance value of $I(i, j)$, and M_0 and V_0 are the desired mean and variance values. Ridge structures in fingerprint are not changed during normalization process. Dynamic levels of variation are standardized.

There are foreground and background regions in an fingerprint image and when segmentation process is applied those regions are clearly separated. Image segmentation is necessary step in many different applications and one of the common task is to determine threshold values [23], [24]. Foreground is clear area of the fingerprint and it contains ridges and valleys. Background is the region outside of clear area and usually does not contain valid information. Foreground region generally has wider gray scale comparing it to background area where the scale is very low. Foreground area is the point of interest with ridges and valleys and background has no valid information for further processing.

The next step is orientation information. Ridge orientation is normally used for detecting, describing and matching minutiae and singular points (upper core, lower core and delta). It defines local orientation of ridges in a fingerprint. There are several algorithms which use this feature. Gradient vectors are one of the most important concepts in image processing and it defines orientation of the ridges locally. Orientation vector is orthogonal to the gradient. Gradient vectoring are used for edge detection. Local ridge frequency is important parameter. Image is divided into blocks of nxn values and this is first step in frequency estimation stage. Next step is to project all the values of the block along a direction orthogonal to ridge orientation previously calculated. Ridge orientation and ridge frequency are used to construct Gabor filter. This filter is used because it has frequency selective and orientation selective properties. Those characteristics allow the filter to be fine tuned for maximum ridge detection at specific orientation and frequency in image. For low quality image, ridge orientation estimation is very important step for automatic fingerprint recognition so, new improvements for orientation estimation and correction are should be proposed and investigated.

Binarization is process where certain threshold value is generated and compared with each pixel in image and changed its value to black or white. For determination of optimal threshold values different approaches can be found in literature [25], [26].

The main purpose is to improve contrast between black pixels (ridges) and white pixels in image (valleys). This contrast leads to emerging minutiae. Contrast improving is common algorithm of image processing used in different applications [27]. Thinning is used on foreground area and main goal is to thin ridges in order to get ridges only one pixel wide. This is done by multiple sub-iterations of thinning algorithm. Usually, shape is similar to skeleton and the technique is called skeletonization. The final result shows if the connections of various ridges are well preserved or not. In [28] enhanced algorithm that was done by adaptive normalization was proposed. Image was divided into sub blocks $(A \times B)$. For each sub block, estimated mean and variance are calculated. Those parameters are determined according to those statistical parameters. We have tested this algorithms on 24×24 sequence. Fingerprint image consists of rows (i) and columns (j) and every pixel has its own intensity level named $I(i, j)$. Normalization processing formula is derived form [8]. M_0 and VAR_0 are mean and variance values which are desired and M and VAR value are mean and variance of the image. M_0 and VAR_0 should be set according to characteristics of image. One of the problems that may occur is that the image can have blurry regions and those regions can have very low quality information. New parameters (adaptive values) can be used in order to deal with this problem. Normalization algorithm consists of three steps: histogram equalization, ROI (region of interest) section selection and adaptive normalization.

3.1 Histogram Matching

Histogram matching is a process in which contrast is adjusted to the desired values and intensity of every pixel is better distributed. The improving of the global contrast is accomplished by adjusting the intensity distribution on a histogram [29]. This technique allows areas of lower local contrast to reach a higher contrast without affecting the global contrast and spreading out the most frequent intensity values. ROI with a lower contrast gain higher contrast after this process.

3.2 ROI Selection

The next step is fingerprint image segmentation. It should be noted that only a region of interest (ROI) is useful area to be recognized for each fingerprint image. Fingerprint image can be taken with high or low fingerprint information depending of various factors. Almost every image has some noise and it is undesirable. That is the reason why area with high information should be selected in advance before any further processing. This can be done by using sub-blocks which are non overlapping with each other in 24×24 sequence. Blocks with a high variance value are selected for the following steps. If parameter V_i is variance of gray for its block, block is classified in:

$$B_{ROI} = B_{ORIGIN}, \quad if\ V_i > V_t \tag{3}$$

where parameter B_{ROI} is region of interest, B_{ORIGIN} is the original image data values and O is block with all zeros. Two step process is advised because fingerprint image can have both homogenous and non-homogenous regions inside image.

3.3 Local Normalization

In the first step, values M_0 and VAR_0 are calculated from statistics of the ROI. Normalization is calculated for ROI of that block. Parameters M_0 and VAR_0 are fixed values.

algorithm 1: Normalization is calculated for ROI of that block. Parameters M_0 and VAR_0 has fixed values

algorithm 2: In the first algorithm, initial parameters M_0 and VAR_0 have fixed values. We changed M_0 and VAR_0 parameters in order to enhance image. This is done by adopting new desired parameters, M_i and VAR_i, for i^{th} block of the ROI, in following equation:

$$M_I = M_o - \alpha_1 * (M_I - M_o) \qquad (4)$$

$$VAR_I = VAR_o - \alpha_2 * (VAR_I - VAR_o) \qquad (5)$$

where α_1 and α_1 are the weighting factors which are contributing to factor of variation. Parameters M_I and VAR_I are previously calculated mean and variance of the i^{th} block. Desired parameters of the above equations are changed according to block properties being calculated.

4 Experimental Results

For testing purposes, we used fingerprint images from NIST database. All images are in 8-bit gray scale and have 512×512 pixels. For this work, partitioned block is 24×24 pixels. On Fig. 2 is original image.

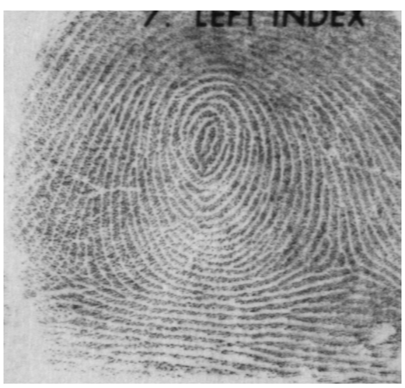

Figure 2: Original fingerprint image from NIST database

During enhancement process various values of parameters are used. Parameters for α_1 and α_2 can be dynamically changed according to image quality and parameters for M_I and VAR_I also can be changed according to image quality.

In Fig. 3, we have shown image normalization. When Algorithm 1 is applied, image quality is acceptable. In given image, results are not well enhanced because local properties were not considered [8, 9]. Fingerprint images contain well defined regions, corrupted regions but with enough information which can be extracted and corrupted regions which is unrecoverable. The purpose of enhancement algorithm is to improve clarity of first two regions and to remove unrecoverable regions. In algorithm 2 local properties were taken into considerations. Number of extracted minutiae was significantly lower when algorithm 2 was applied. In Fig. 3, low quality image was normalized and number of extracted minutiae was over 150. Also, a large number of spurious minutiae was detected. After block processing was applied, number of extracted minutiae was decreased below 120 which is not ideal but acceptable (Fig. 4).

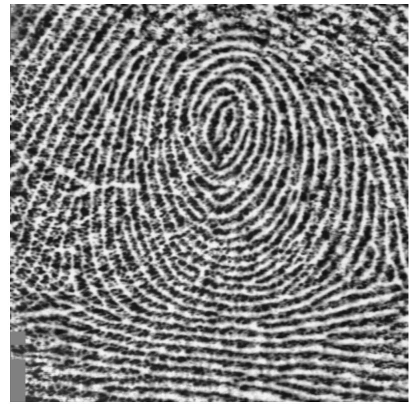

Figure 3: Enhanced image

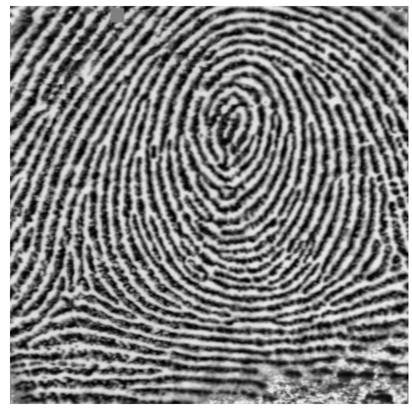

Figure 4: Enhanced image after block processing

5 Conclusion

Considering that fingerprint images originating from different sources could be different in terms of quality, often some enhancement algorithms are required. The main task of enhancement algorithms is to create an fingerprint image that does not contain artificially generated ridge structures that might later lead to the detection of false minutiae features. Enhancement process should significantly improve the matching performance over a large number of fingerprints.

In this work we proposed modification of fingerprint enhancement normalization for image by taking into consideration properties of local region. Selection of ROI method is suggested by using statistics of the block. Block based fingerprint image enhancement could be used for number of extracted minutiae decrease when images are poor quality.

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