Image Enhancement for Fingerprint Minutiae-Based Algorithms Using CLAHE, Standard Deviation Analysis and Sliding Neighborhood

M. Sepasian, W. Balachandran and C. Mares

Abstract*—the purpose of this paper is to investigate the performance of a three-step procedure for the fingerprint identification and enhancement, using CLAHE (contrast limited adaptive histogram equalization) together with 'Clip Limit', standard deviation and sliding neighborhood as stages during processing of the fingerprint image. Firstly, CLAHE with clip limit is applied to enhance the contrast of the small tiles existing in the fingerprint image and to combine the neighboring tiles using a bilinear interpolation in order to eliminate the artificially induced boundaries. In a second step, the image is decomposed into an array of distinct blocks and the discrimination of the blocks is obtained by computing the standard deviation of the matrix elements to remove the image background and obtain the boundaries for the region of interest. Finally, by using a slide neighborhood processing, an enhancement of the image is obtained by clarifying the Minutiae (endpoints and bifurcations) in each specific pixel, process known as thinning. The paper presents the motivation for developing this method, its phases, and its possible advantages through a simulated investigation.

Index Terms*— Fingerprint, *CLAHE, Standard Deviation and Sliding Neighborhood

I. Introduction

In fingerprint minutiae-based matching, features are extracted from two fingerprints and stored as sets of points in a two-dimensional plane. Two options are available for minutiae points: endpoints and bifurcations and combined they form up to a total of 30 minutiae points on average in one print [8]. The performance of feature extraction algorithms depend on the input fingerprint images and usually a fingerprint image enhancement is applied to obtain an enhanced output image through a set of intermediate steps. Various techniques have been published in the scientific literature, which are used to enhance the grey level of the fingerprint images. The majority are based on the information about the local ridge structure in term of estimation of the local ridge orientation from input fingerprint images. However, such algorithms are fine for good quality images but their performances decrease drastically when low quality images are used, due to the noise (creases, smudges, and holes…). This paper presents an enhancement algorithm that can produce good fingerprint matching when used on poor quality images.

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II. Fingerprint Images Enhancement Levels

Fingerprint images include unnecessary information such as scars, moist or areas without valuable ridges and furrows, and in order to eliminate the redundant information and filter the useful information, a specific process using the following four steps is designed:

A. *Normalization:*

Histogram equalization is a general process used to enhance the contrast of images by transforming its intensity values [2]. As a secondary result, it can amplify the noise producing worse results than the original image for certain fingerprints. Therefore, instead of using the histogram equalization which affects the whole image, CLAHE (contrast limited adaptive histogram equalization) is applied to enhance the contrast of small tiles and to combine the neighboring tiles in an image by using bilinear interpolation, which eliminates the artificially induced boundaries. In addition, the 'Clip Limit' factor is applied to avoid over-saturation of the image specifically in homogeneous areas that present high peaks in the histogram of certain image tiles due to many pixels falling inside the same gray level range [2]. Additionally, a combination of filters in both domains, spatial and Fourier is used to obtain a proper enhanced image.

B. *Binarization:*

During this phase the gray scale image is transformed into a binary image by computing the mean value of each 32-by-32 input block matrix and transferring the pixel value to 1 if larger than the mean or to 0 if smaller.

C. *Quality markup:*

In this phase, the useless data is removed, in order to separate the fingerprint image from the background or any unnecessary details before analysis; the algorithm is based on distinct block processing by calculating the standard deviation of the array to each distinct 8 by 8 block of image and padding image with 0's if necessary; finally the

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background image is removed in order to obtain the boundaries for the region of interest for each subset of matrices having a higher value than the threshold.

D. Thinning:

During this stage, the characterization of each feature is carried out by determining the value of each pixel; some techniques exist based on thinning the pixel neighborhood having a maximum value initially (16) and filtered in the final phase (1) in order to eliminate the false lonely points and breaks; an algorithm is presented which eliminates the false information by slide neighborhood processing in a first step followed by thinning without any additional filtering; finally, the fingerprint image is separated from the background and local minutiae are located on the binary thinned image.

III. HISTOGRAM EQUALIZATION:

As a first step of the fingerprint image enhancement process, histogram equalization is applied to enhance the image's contrast by transforming the intensity values of the image (the values in the color map of an indexed image), which are given by the following equation:

$$s_k = T(r_k) = \sum_{j=1}^{k} p_r(r_j) = \sum_{j=1}^{k} \frac{n_j}{n} \qquad (1)$$

Where s_k is the intensity value in the processed image corresponding to r_k in the input image, and $p_r\ (r_j)$ =1, 2, 3... L is the input fingerprint image intensity level. In other words, the values in a normalized histogram approximate the probability of occurrence of each intensity level in the image. In the following figures the differences between the histogram of the normal fingerprint before (1) and after (2) histogram equalization (implemented in the MATLAB Image processing toolbox by function "histeq") are depicted [11].

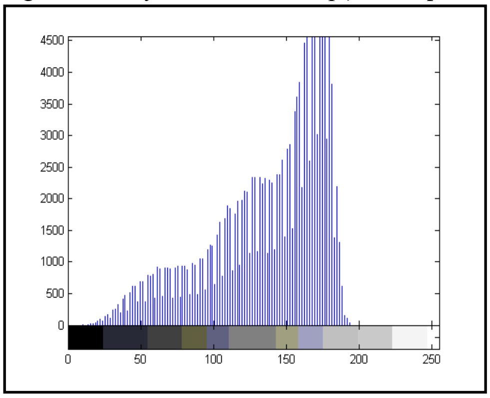

Figure (1) Histogram of original fingerprint image

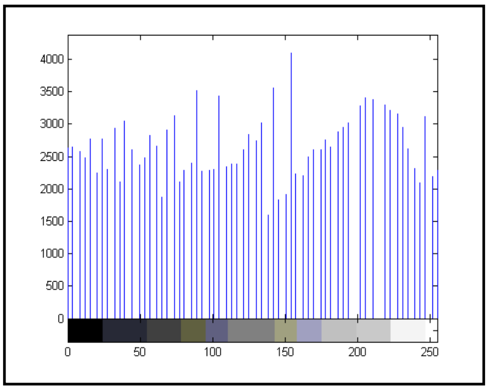

Figure (2) After Histogram equalization

Figure (3) Original fingerprint

Figure (4) After Histogram equalization

However, by enhancing the contrast of an image through a transformation of its intensity values, the histogram equalization can amplify the noise and produce worse results than the original image for some fingerprints, due to many pixels falling inside the same gray level range. Therefore, instead of applying the histogram equalization, which works on the whole image, CLAHE (contrast limited adaptive histogram equalization) is used to enhance the contrast of the small tiles of an image and to combine the neighboring tiles using a bilinear interpolation which will eliminate the artificially induced boundaries.

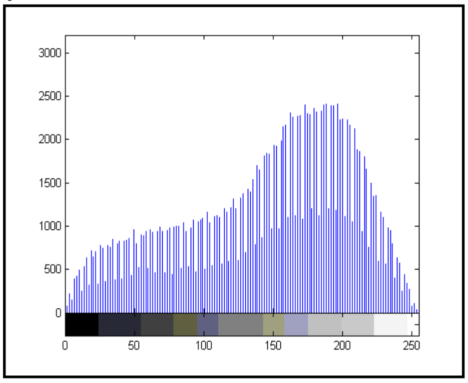

Figure (5) After CLAHE

In addition, 'Clip Limit' factor (implemented in the MATLAB Image Processing Toolbox by the function "adapthisteq (f,"clipLimit") is applied to avoid the over-saturation of the image, specifically in homogeneous areas which display a high peak in the histogram of the particular image tile. The images in Figures 2, 5 and 6 are the histogram-equalized results of same fingerprint image and improvements in average intensity and contrast are obvious. In addition, the spread of the histogram over the entire intensity is increasing the contrast and the average intensity level in the histogram of the equalized image is higher (lighter) than the original.

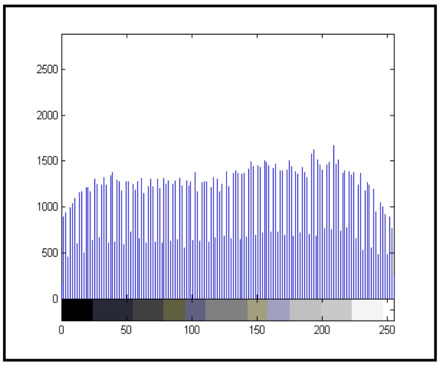

Figure (6) After CLAHE with Clip Limit

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Figure (7) Original fingerprint

Figure (8) After CLAHE with Clip Limit

The images in Figures 9, 10 and 11 are the plot of different histogram-equalized results of the same fingerprint image. It is quite evident that the narrow range of the color (25-200) is transformed into full intensity scale in the output fingerprint image but in a different color scatter plot, and this process can reduce the noise amplification in the fingerprint image.

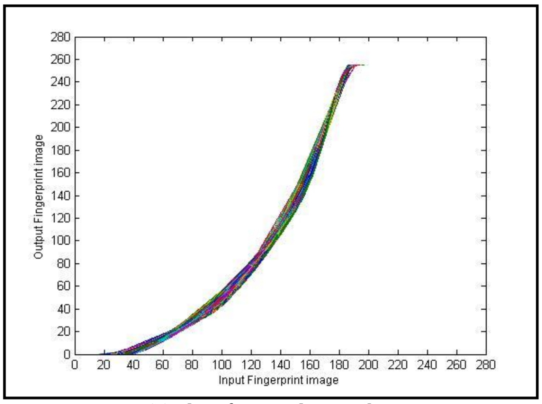

Figure (9) plot of original image histogram, after histogram equalization

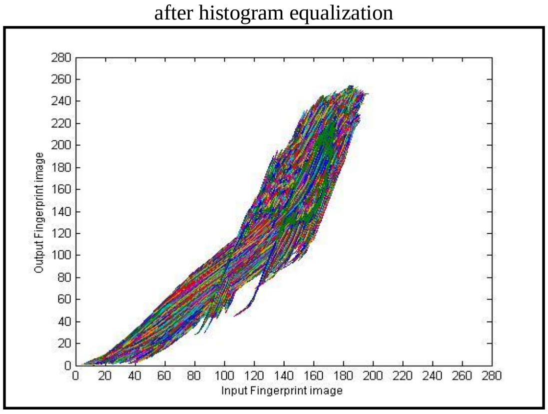

Figure (10) plot of original image histogram, after CLAHE

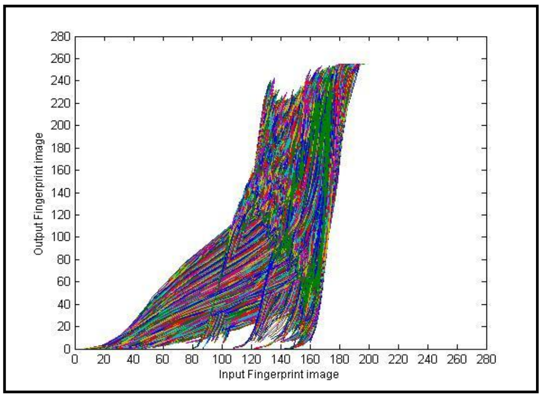

Figure (11) plot of original image histogram, after CLAHE With Clip Limit

IV. Spatial and Fourier domain filtering

Sherlock and coworkers [12] enhanced the fingerprint image in the Fourier domain, based on convolving each image with pre-computed filters of the same size that the processed image. However, their algorithms do not use the full contextual information provided by the fingerprint image because of the assumptions that the ridge frequency is constant throughout the image, and decreases the number of pre-computed filters.

In addition, Watson and coworkers [13] proposed a different approach by enhancing the fingerprint image completely in the Fourier domain. Their algorithm based on the "root filtering" technique [14], divides the fingerprint into overlapping blocks, and is then used within the process of the image enhancement: [10]

$$I_{enh}(x,y) = FFT^{-1}\left\{F(u,v)\left|F(u,v)\right|^{k}\right\} \qquad (2)$$

$$F(u,v) = FFT(I(x,y))$$

The main advantage of their approach is that the computation of intrinsic images for this operation does not require increasing the dominant spectral components while attenuating the weak components. Therefore, as a second step, a two-dimensional Inverse Fast Fourier Transform (IFFT) is applied to enrich a particular M x N matrix by its dominant frequencies, this being equivalent to calculating the two-dimensional inverse discrete Fourier transform (IDFT), defined by the following equation:

$$f(x,y) = \frac{1}{MN}\sum_{n=0}^{M-1}\sum_{m=0}^{N-1} F(m,n)\, e^{j\frac{2\pi mx}{M}} e^{j\frac{2\pi ny}{N}} ; 0 \le x \le M-1, 0 \le y \le N-1 \qquad (3)$$

The dimensions of the input block (M x N) must be of order of a power of 2. When working with other input sizes, one can use the Pad block to pad or truncate these dimensions. However, the product of the functions is computed at every point of overlap, which can produce a significant error with respect to manifestation of minutiae by stretching the ridges, producing a puncture or a break in the ridges. Different sets of pixels in each block will produce different results after using the IFFT and in the following example, after carrying out some tests; the fingerprint image is partitioned into 16×16 matrix blocks.

Figure (12) After IDFT

In addition, Aguilar and coworkers [10], after analyzing various solutions used a combination of filters in both domains, spatial and Fourier to obtain a proper enhanced image. Their algorithm is based on algebraic sum of two enhanced images in which the resulting pixel will be white, if in the both images is white. They used the Gabor elementary functions to represent generic 2D images. While the compact support of the Gabor kernel is useful from a time-frequency analysis perspective, its use does not necessarily result in an efficient image enhancement method. The even symmetric form of the Gabor elementary function that is oriented at a zero angle is given by:

$$G(x,y) = \exp\left\{-\frac{1}{2}\left[\frac{x^2}{\delta_x^2}+\frac{y^2}{\delta_y^2}\right]\right\}\cos(2\pi f x) \quad (4)$$

Where f is the ridge frequency and the choice of δ_x^2 and δ_y^2 determines the shape of the filter envelope and the trade-off between enhancement and spurious artifacts [10].

Figure (13) After Gabor filter

V. Fingerprint Image Binarization

The fingerprint binarization is an algorithm producing a 1-bit type image, with 0 as ridges which are tinted with black and 1 as valleys which are tinted with white. However, the adaptive binarization method is based on a threshold t, with gray-level pixels lower than t assigned to 0 and the others to 1. It is known that dissimilar fingerprint images have special contrast and intensity, and therefore, a unique threshold t is not proper for a general fingerprint image analysis. The local threshold technique changes t locally, by adapting its value to the average local intensity. In this paper this method is applied based on determining the mean value of each 32-by-32 input matrix and transferring the pixel value to 1 if it is larger than mean and to 0 if it is smaller. However, in very poor quality fingerprint images, the local threshold method cannot guarantee acceptable results and a special threshold, which has sufficient effect, is required. This threshold having sufficient affection was determined on the tested database presented in this paper.

Figure (14) After Binarization

VI. Foreground and Background Detection

In general, a fingerprint image contains ridges described by bright pixels and valleys by dark pixels plus some blank space near the edges, but normally the blank spaces are not valuable due to the noise of the image in this area. As a consequence, the image area without valuable ridges and furrows must be excluded from fingerprint image. The valuable remaining area is sometimes known as ROI (Region of Interest). The algorithm presented in this paper is based on distinct image block processing by computing the standard deviation of the array to each distinct M X N block of image and padding the image with 0's if necessary.

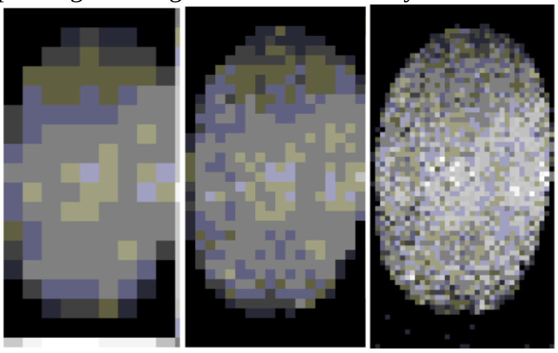

Figure (15) fingerprint after standard deviation
(left 32*32 pixels, middle 16*16, and 8*8 right)

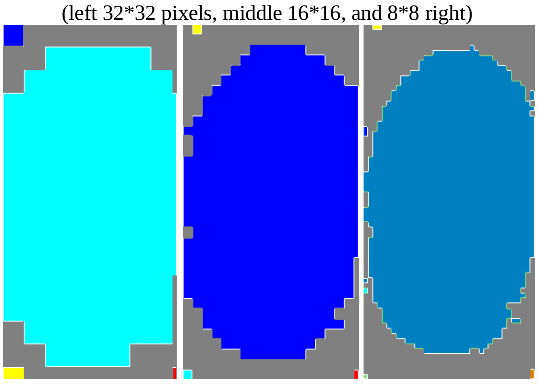

Figure (16) boundaries of fingerprint after standard deviation
(Left 32x32 pixels, middle 16x16, and right 8x8)

In order to remove the image background and obtain the region of interest, boundaries of each set of matrices with higher value than the threshold are separated from the rest. As shown in Figure 16, by using a different size of the matrix set, results in different boundaries and in this paper, after numerical experiments, an 8 x 8 matrix is selected.

VII. Thinning

Thinning is the last step of the fingerprint image enhancement before feature extraction, and it is used in order to clarify the endpoints and the bifurcations in each specific pixel, subject to the numbers of pixels belonging to these features in the original fingerprints.

Different thinning algorithms and techniques have been developed but they are based on thinning the neighborhood of the pixels that have maximum values in a sequential process obtaining a characteristic pixel value for each feature at each step. In addition, because of false H breaks and lonely points which could appear when using such algorithms (Figure 17), the fingerprint images have to be filtered in order to remove them. In this paper an algorithms has been developed, which eliminates the development of such false information in a fingerprint image by using initially a slide neighborhood processing and then thinning the result in only one step without any intermediate filtering and with a substantial reduction of the computational complexity.

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Figure (17) affection of thinning without Sliding Neighborhood in fingerprint image

A set of neighborhood rectangular blocks is defined by their locations relative to the center pixel, and the analysis is performed a pixel at a time, with the value of any given pixel in the output image being determined by the application of an algorithm to the values of the corresponding input pixel's neighborhood.

Figure (18) fingerprint after slide neighboring
(Left 2x2 pixels, middle 3x3, and 5x5 in right)

As shown in Figure 18, the selection of different sets of blocks results in different outputs and if the size of the block is bigger that 3x3, discontinuous ridges will be produced in the fingerprint image. Therefore, 2x2 set of matrices are applied in this step to avoid any discontinuous ridges.

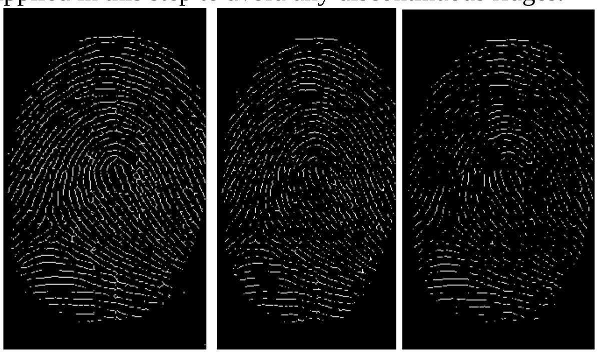

Figure (19) fingerprint after thinning
(Left 2x2 pixels, middle 3x3, and 5x5 right)

VIII. Conclusions

Different methods in the public domain for fingerprint image enhancement have been reviewed, and a new methodology allowing superior performances is proposed. In order to avoid specific shortfalls of this process, the procedure follows first the application of CLAHE with Clip Limit in order to enhance the contrast of small tiles, to eliminate the artificially induced boundaries and to avoid over-saturation of the image specifically in homogeneous areas. In addition, a combination of filters in both domains, spatial and Fourier is used to obtain a proper enhanced image. Some possible new developments have been carried out especially by applying the standard deviation analysis of the array to each distinct M x N blocks of image in order to remove the background and obtain the region of interest. The last phase of this new enhancement methodology is the application of the slide neighborhood processing to obtain a thinned fingerprint image without any intermediate filtering and substantial reduction of the computational complexity. The analysis of its possible advantages is carried out through a simulated investigation.

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