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Two Stage Block-Wise Fingerprint Enhancement Using Discrete Wavelet Transform

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Abstract--**Fingerprint authentication is one of the highest levels of reliability and has been extensively used by forensic experts in criminal investigations. Low-quality fingerprint images always exist with cracks, scars, dry skin, poor ridges and valleys contrast of these images. We propose an effective two-stage block wise enhancement scheme in spatial and frequency domain by learning from underlying images. In the first stage, the fingerprint image is enhanced in spatial domain with a spatial ridge-compensation filter. Second-Stage enhances the First-Stage image using Discrete Wavelet Transform in the frequency domain.**

Keywords--Fingerprint Enhancement, learning, Discrete Wavelet Transform, Wavelet Packet Decomposition.

I. INTRODUCTION

Biometrics is the science of recognizing an individual based on physical or behavioural characters. The Fingerprint is one of the Biometric indicators that are used by forensic experts in criminal investigation, because of its universality, permanence, distinctiveness and accuracy. Input Fingerprint images are of low quality because of wetness, dryness, smears in the skin. In order to provide better clarity, these input fingerprint images are enhanced using two stage block wise enhancement scheme. The first stage enhances the input fingerprint image by connecting the broken ridges and separating the merged ridges. Even though the first stage enhances the image, the output of the first stage will be a blurred image. This blurred image will be enhanced in the second stage using DWT. A discrete wavelet transform is any wavelet transform, for which the wavelets are discretely sampled. As with other wavelet transforms, a key advantage it has over Fourier transforms is temporal resolution: it captures both frequency and location information.

In section II, the discussion of related work is carried out. In section III, the first stage enhancement of fingerprint is explained. In section IV, the second stage enhancement of fingerprint is explained. In section V, the Minutiae Extractions and performance evaluations are discussed. In section VI, the experimental results are discussed. In section VII, the two stage block-wise enhancement scheme is concluded, followed by the references used.

II. RELATED WORKS

The primary focus of [1] is to enhance the fingerprint images. This scheme first enhances the fingerprint image in the spatial domain with a spatial ridge-compensation filter by learning from the images. In the first-stage enhancement the broken ridges will be connected and the merged ridges will be separated effectively; thus, the fingerprint ridges can be recovered well. With the help of the first step, the second-stage filter, i.e., a frequency bandpass filter that is separable in the radial- and angular-frequency domains, is employed. It is noted that the parameters of the bandpass filters are learnt from both the original image and the first-stage enhanced image instead of acquiring from the original image solely. It enhances the fingerprint image significantly because of the fast and sharp attenuation of the filter in both the radial and the angular-frequency domains. The author [2] deals with some core issues related to the design of these systems and provide a novel modular framework, namely, novel approaches for biometric systems (NABS) that have implemented to address them. NABS encompasses two possible architectures based on the comparative speeds of the involved biometrics. It also provides a novel solution for the data normalization problem, with the new quasi-linear sigmoid (QLS) normalization function. This function can overcome a number of common limitations, according to the presented experimental comparisons. A further contribution is the system response reliability (SRR) index to measure response confidence. Its theoretical definition allows to take into account the gallery composition at hand in assigning a system reliability measure on a single-response basis. The unified experimental setting aims at evaluating such aspects, both separately and together, using face, ear, and fingerprint as test biometrics. The author [3] provide an effective algorithm of fingerprint image enhancement, which can much improve the clarity and continuity of ridge structures based on the multiresolution analysis of global texture and local orientation by the wavelet transform. Experimental results show that the enhanced image quality by using the wavelet-based enhancement algorithm is much better than the other existing methods for improving the minutiae detection. The author [4] presents a fingerprint recognition system based on a novel application of the classifier DECOC to the minutiae extraction and on an optimized matching algorithm . To identify the different shapes and types of minutiae, a Data-driven Error Correcting Output Coding (DECOC) has been adopted to work as a classifier. This method has been applied throughout the fingerprint skeleton to locate various minutiae. Extracted minutiae have been used then as identification marks for an automatic fingerprint matching that is based on distance and direction between two minutiae and type of minutiae. The author [5] presents the extraction of minutiae from fingerprint images. A critical step in automatic fingerprint matching is to reliably extract minutiae from the input fingerprint images. This paper presents a review of a large number of techniques present in the literature for extracting fingerprint minutiae. The techniques are broadly classified as those working on binarized images and those that work on grey scale images directly. The author [6] evaluates the performance of the fingerprint images. This method presents a fast fingerprint enhancement algorithm, which can adaptively improve the clarity of ridge and valley structures of input fingerprint images based on the estimated local ridge orientation and frequency. This method evaluates the performance of the image enhancement algorithm using the goodness index of the extracted minutiae and the accuracy of an online fingerprint verification system. Experimental results show that incorporating the enhancement algorithm improves both the goodness index and the verification accuracy.

III. FIRST-STAGE ENHANCEMENT

The first stage enhances the input fingerprint image by connecting the broken ridges and separating the merged ridges. First stage enhancement consists of three steps.

A. Local Normalization

This step is used to reduce the local variations and standardize the intensity distributions in order to consistently estimate the local orientation. The block wise operation does not change the clarity of the ridge and furrow structures, but reduces the variations in grey-level values along ridges and furrows, which facilitates the subsequent processing steps. Sobel Filter is used in this step. The color of the ridges turned to be white, where the background turns black. This filter provides effective thinning to the ridges based on the window size. The Sobel operator is used in image processing, particularly within edge detection algorithms. Technically, it is a discrete differentiation operator, computing an approximation of the gradient of the image intensity function. At each point in the image, the result of the Sobel operator is either the corresponding gradient vector or the norm of this vector. The Sobel operator is based on convolving the image with a small, separable, and integer valued filter in horizontal and vertical direction and is therefore relatively inexpensive in terms of computations. On the other hand, the gradient approximation that it produces is relatively crude, in particular for high frequency variations in the image.

The operator uses two 3×3 kernels which are convolved with the original image to calculate approximations of the derivatives - one of horizontal changes, and one for vertical. If we define **A** as the source image, and $\mathbf{G}_x$ and $\mathbf{G}_y$ are two images which at each point contain the horizontal and vertical derivative approximations, the computations are as follows:

$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix} * \mathbf{A} \quad \text{and} \quad \mathbf{G}_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * \mathbf{A}$$

Where $*$ here denotes the 2-dimensional convolution operation.

Since the Sobel kernels can be decomposed as the products of an averaging and a differentiation kernel, they compute the gradient with smoothing.. At each point in the image, the resulting gradient approximations can be combined to give the gradient magnitude, using

$$\mathbf{G} = \sqrt{\mathbf{G}_x{}^2 + \mathbf{G}_y{}^2}$$

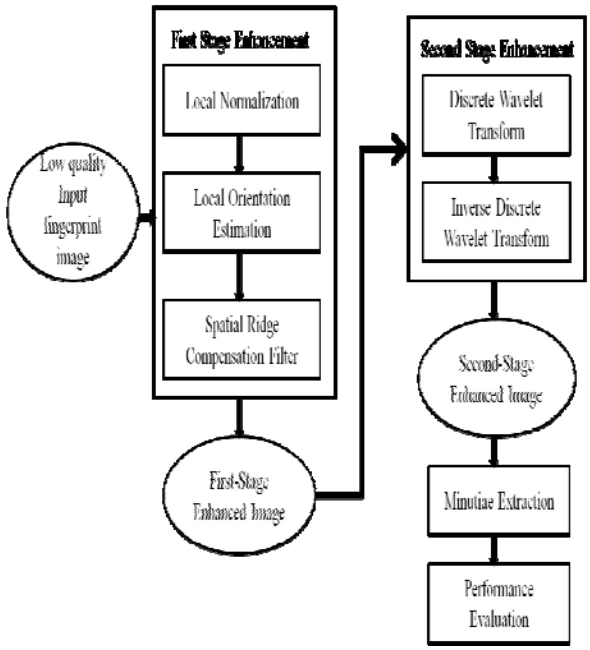

Fig 1. Architecture of Two Stage Block-Wise Enhancement

B. Local Orientation Estimation

This step determines the dominant direction of the ridges in different parts of the fingerprint image. We used the gradient method for orientation estimation and an orientation smoothing method.

Gradient method is an algorithm to solve problems of the form,

$$\min_{x \in \mathbb{R}^n} f(x)$$

with the search directions defined by the gradient of the function at the current point. Examples of gradient method are the gradient descent and the conjugate gradient. Gradient descent is to find a local minimum of a function. Gradient descent is also known as steepest descent, or the method of steepest descent. Large efforts are made in order to extract reliable orientation data from fingerprints. Many methods for ridge orientation estimation exist. Unfortunately, the determination of ridge orientation becomes more difficult when image quality is low. Thus, even the 'best' orientation estimation algorithm will fail in regions of low image quality. To encounter this problem, the ridge orientation is smoothed. Only small regions can be smoothed successfully. Smoothing operation will apply a filter to the image. The most common type of filters is linear, in which an output pixel's value (i.e. g(i,j) is determined as a weighted sum of input pixel values (i.e. f(i+j,j+l)) :

$$g(i,j) = \sum_{k,l} f(i+k, j+l)\, h(k,l)$$

h(k,l) is called the kernel, which is nothing more than the coefficients of the filter. It helps to visualize a filter as a window of coefficients sliding across the image.

C. Spatial Ridge Compensation Filter

The Spatial Ridge Compensation Filter performs ridge compensation along the ridges in the spatial field. Block wise comparison is made in this step. This step enhances the fingerprint's local ridges using the neighbour pixels in a small window with a weighted mask along the orientation of the local ridges. Each pixel in the fingerprint is replaced with its weighted neighbour sampling pixels in a small window and with the controlled contrast parameters along the orientation of the local ridges. This step produces the first stage enhanced image. Even though the first stage enhances the image, the output of the first stage will be a blurred image. To enhance the image further, the first stage enhanced image is given as input to the second stage enhancement.

IV. Second-Stage Enhancement

Second-Stage Enhancement uses Discrete Wavelet Transform to enhance the first stage image and provides better clarity to the image. In numerical analysis and functional analysis, a discrete wavelet transform is any wavelet transform , for which the wavelets are discretely sampled. As with other wavelet transforms, a key advantage it has over Fourier transforms is temporal resolution: it captures both frequency and location information. Wavelet decomposition, the generic step splits the approximation coefficients into two parts. After splitting we obtain a vector of approximation coefficients and a vector of detail coefficients, both at a coarser scale. The information lost between two successive approximations is captured in the detail coefficients. Then the next step consists of splitting the new approximation coefficient vector; successive details are never reanalyzed. In the corresponding wavelet packet situation, each detail coefficient vector is also decomposed into two parts using the same approach as in approximation vector splitting. This offers the richest analysis: the complete binary tree is produced as shown in the following figure.

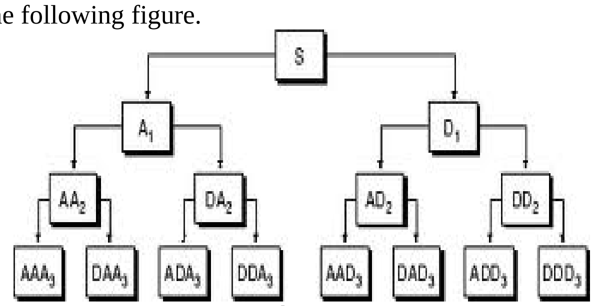

Fig 2. Wavelet Decomposition

For n levels of decomposition the Wavelet Packet decomposition (WPD) produces 2^n different sets of coefficients (or nodes) as opposed to (3n + 1) sets for the DWT. However, due to the down sampling process the overall number of coefficients is still the same and there is no redundancy. From the point of view of compression, the standard wavelet transform may not produce the best result, since it is limited to wavelet bases that increase by a power of two towards lower frequencies. It could be that another combination of bases produces a more desirable representation for a particular signal.

Perform a level 2 decomposition of the image.
The steps are,

- Extract the level 2 approximation coefficients.
- Reconstruct the Level 2 approximation and the Level 1 and 2 details.
- Inverse Wavelet Transform. (Reverse of DWT).

V. Minutiae Extraction And Performance Evaluation

A fingerprint is a unique pattern of ridges and valleys on the surface of a finger of an individual. A ridge is defined as a single curved segment, and a valley is the region between two adjacent ridges. Minutiae points are the local ridge discontinuities, which are of two types: ridge endings and bifurcations. A ridge ending is defined as the point where a ridge ends abruptly. A ridge bifurcation is defined as the point where a ridge forks or diverges into branch ridges. A good quality image has around 40 to 100 minutiae. It is these minutiae points which are used for determining the uniqueness of a fingerprint.

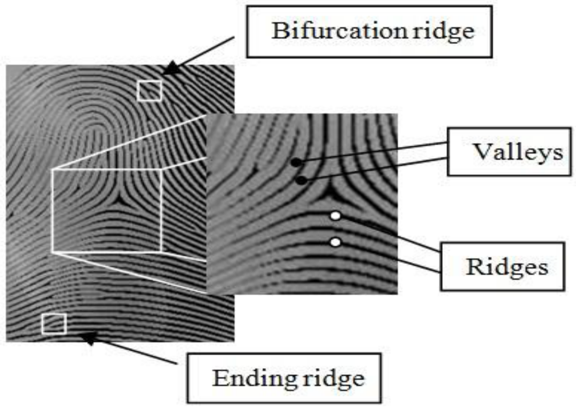

Fig 3. Ridges, Valleys and Minutiae Points

Marking minutiae accurately and rejecting false ones is very important. However, fingerprint images get degraded and corrupted due to variations in skin and impression conditions. Thus, image enhancement techniques are employed prior to minutiae extraction.
The performance of the fingerprint image will be evaluated by comparing the PSNR ratio calculated from the first stage image and the second stage image.

VI. Experimental Results

In figure 4, (a) is the input low quality fingerprint image which undergoes two stage enhancement and (b) and (c) are the first and second stage enhanced images. This method can be applied to various low quality fingerprint images and the experimental results obtained show that the enhanced image is better than earlier enhancement techniques

(a) (b) (c)

Fig.4. (a) original image (b) first-stage enhanced image (c) second stage enhanced image

Table 1 shows the TMR, FMR, DMR, EMR and PSNR values for the original, first stage and second stage images. The PSNR value in the original image is infinite, because the reference and the input image are same.

Table 1. TMR, FMR, DMR, EMR and PSNR values for the image (a)

	TMR (%)	FMR (%)	DMR (%)	EMR (%)	PSNR
Original image	92.08	3.76	4.19	4.16	Infinite value
First-stage enhancement	96.59	3.60	2.05	2.80	+26.71dB
Second-stage enhancement	99.40	3.45	0.84	1.88	+42.06dB

VII. CONCLUSION

In this paper, an effective two stage block wise enhancement scheme for low quality fingerprint images has been proposed. In the first stage the fingerprint ridges are recovered, and the clarity of the image is improved in the second stage. This block-wise scheme reduces the computation complexity and also improves speed. The experimental results show that this method is able to handle various input images and achieves the best performance when implemented.

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