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Image Enhancement Techniques for Fingerprint Identification

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Abstract—The aim of this paper is to propose a new method in fingerprint enhancement with application of wavelet transform which is more efficient than existing methods. At present the methods that are in use are the ones involving the use of Gabor filtering and Fourier filtering. But the accuracy of these techniques is far from satisfactory. A new technique is being proposed that incorporates wavelet transform and Gabor filtering. The performance of this technique is being discussed in the paper.

Index Terms—Wavelet Transform, Fourier Transform, Gabor Filtering, Fingerprint Enhancement, Wavelet Decomposition, Reconstruction, Segmentation.

I. INTRODUCTION

Fingerprints have been used for over a century and are the most widely used form of biometric identification. Fingerprint identification is commonly employed in forensic science to support criminal investigations, and in biometric systems such as civilian and commercial identification devices. The fingerprint of an individual is unique and remains unchanged over a lifetime. A fingerprint is formed from an impression of the pattern of ridges on a finger. 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 [3].

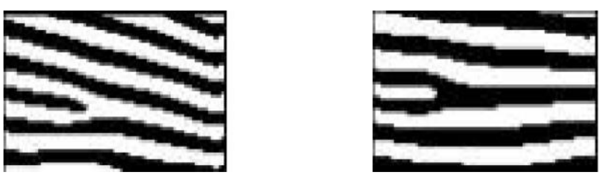

Figure 1: Example of a ridge ending and a bifurcation.

Fingerprint images are rarely of perfect quality. They may be degraded and corrupted with elements of noise due to many factors including variations in skin and impression conditions. This degradation can result in a significant number of spurious minutiae being created and genuine minutiae being ignored. A critical step in studying the statistics of fingerprint minutiae is to reliably extract minutiae from fingerprint images. Thus, it is necessary to employ image enhancement techniques prior to minutiae extraction to obtain a more reliable estimate of minutiae locations.

This paper consists of three parts. Firstly image enhancement technique involving the Fourier Transform is discussed. Secondly, image enhancement using of Gabor filters are discussed. Finally the implementation of wavelet transform to enhance the image for improved efficiency and accuracy is discussed.

II. ENHANCEMENT TECHNIQUES

A. Enhancement using 2 D Fourier Transform

This technique mainly consists of four stages: Normalization, Segmentation, Orientation Estimation and Fourier Filtering. The steps are explained in detail below:

1. Normalisation: This step is done to reduce the differences in the grey level values along the ridges and valleys so that the pixel values in the image have a specified mean and variance. First the mean (M) and variance (V) of the image is computed, then the equations shown below were used to calculate the values for the normalised image where, I(i,j) is the gray-scale value at pixel (i,j), M_0 and V_0 are the desired mean and variance respectively, and G is the normalised image.

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

The desired mean and variance were chosen to be 0 and 1 respectively, so that the new intensities of the pixels for the normalised image would mostly be between -1 and 1 (taking standard deviation as 1 on either side of the mean), making subsequent calculations easier.

2. Segmentation: This step is done to separate the actual fingerprint area from the image background. The

image is divided into many blocks and the std deviation is calculated form the local neighborhood. A threshold is set to exclude the background from the fingerprint area.

3. Orientation Image Estimation: This step is done to estimate the orientation of the image. The process is carried out by placing an image window at a point in the raw image. The window is rotated in 16 equally spaced directions and the projections are calculated along the y direction. The projection with maximum variance is fixed as the orientation of the pixel. This is continuously done to obtain the values for all the pixels.
4. Filtering: The image is converted from the spatial domain to frequency domain by application of 2D Fourier Transform. This image is then filtered through 16 Butterworth filters with each filter tuned to a particular orientation. The number of directional filters corresponds to the set of directions used to calculate the orientation image. After each directional filter has been independently applied to the Fourier image, the inverse Fourier transform is used to convert each image back to the spatial domain, thereby producing a set of directionally filtered images called prefiltered images [5].
5. Reconstruction: The next step in the enhancement process is to construct the final filtered image using the pixel values from the prefiltered images. This requires the value of the ridge orientation at each pixel in the raw image and the filtering direction of each prefiltered image. Each point in the final image is then computed by selecting, from the prefiltered images the pixel value whose filtering direction most closely matches the actual ridge orientation. The output of the filtering stage is an enhanced version of the image that has been smoothed in the direction of the ridges.

B. Enhancement using Gabor Filters

This technique is an improvement over the previous method in the sense that in this technique the frequency of the image is also taken into account as compared to previous method where in the frequency was taken to be constant through out.

This technique consists of mainly 5 steps: Normalisation, Segmentation, Orientation Image Estimation, Frequency Image Estimation and Filtering.

1. Normalisation: As discussed in II A.
2. Segmentation: As discussed in II A.
3. Orientation Image Estimation: The orientation [illegible] Figure 2 shows the x and y sobel [illegible] the Sobel operator

-1	-2	-1		-1	0	1
0	0	0		-2	0	2
1	2	1		-1	0	1

Figure 2: Sobel mask in x direction (left) and sobel mask in y direction (right) for calculating gradients

masks, which are convolved with the normalised image to get the gradients in the x and y directions. The moments (sum of the doubled angles of the gradients within the block) are then computed for each block using the expressions shown below, to remove circularity of angles (0° and 180° point in the same direction).

$$V_x(i,j) = \sum_{u=i-\frac{w}{2}}^{i+\frac{w}{2}} \sum_{v=i-\frac{w}{2}}^{i+\frac{w}{2}} 2\partial_x(u,v)\partial_y(u,v)$$

$$V_y(i,j) = \sum_{u=i-\frac{w}{2}}^{i+\frac{w}{2}} \sum_{v=i-\frac{w}{2}}^{i+\frac{w}{2}} \partial_x^2(u,v) - \partial_y^2(u,v)$$

$V_x(i,j)$ and $V_y(i,j)$ are the moments in x direction and y direction respectively, centered at pixel (i,j), ∂x and ∂y are the x and y gradients and w is the block size, taken as 8. The orientation of each block is computed using the following expression, where θ is the orientation angle

$$\theta(i,j) = \frac{1}{2}\tan^{-1}\frac{V_y(i,j)}{V_x(i,j)}$$

4. Frequency Orientation Estimation: This estimates the approximate ridge frequency for the finger print image by dividing it into blocks of 8 x 8 pixels. For any local neighbourhood which does not have singularities, the gray-levels of the pixels form a sinusoidal shape along the direction orthogonal to the ridge orientation for that local neighborhood. An oriented window (oriented in the direction orthogonal to the local ridge orientation) is used to approximate this sinusoid. The inverse of the average distance between the number of peaks encountered is the local frequency of that block.

5. Gabor Filtering: Filtering is performed finally to remove noise and preserve the ridge structures. The normalised image is filtered by a bank of Gabor filters (band pass filter), tuned to the corresponding local frequency and orientation for each local neighbourhood. A Gabor filter in the spatial domain is a sinusoidal wave modulated by a Gaussian envelope. The Gabor filters have both frequency selective and orientation selective properties, thus they use the orientation image and the frequency image to filter the normalised image.

   The general form of a Gabor filter is where ∂_x and ∂_y are the standard deviations of the Gaussian envelope along the x and y axes, respectively, φ is the orientation of the filter, and f is the frequency of the sinusoidal wave. The filtering removes noise from the normalised image

$$h(x,y,\varphi,f) = \exp\left(-\frac{1}{2}\left(\frac{x_\varphi^2}{\partial_x^2} + \frac{y_\varphi^2}{\partial_y^2}\right)\right)\cos(2\pi f x_\varphi)$$

$$x_{\varphi} = x\cos\varphi + y\sin\varphi$$

$$y_{\varphi} = -x\sin\varphi + y\cos\varphi$$

C. Enhancement using Wavelet Transform and Gabor Filtering

This method uses wavelet transform for denoising and increases the contrast between the ridge and background by using a map function to the wavelet coefficient set, and thereafter, the Gabor filter method can further enhance the ridge using the orientation and frequency information.

1) Wavelet Decomposition

A discrete wavelet transform can be used to compute the multi-resolution representation of signals (rows and columns of images in this study). Approximation of a signal $c(A_{j+1})$ the coefficient of A_{j+1} , also known as the trend, can be obtained by convolving the input signal cAj with the low pass filter. Down sampling is done by keeping one column or one row out of two (a pixel in this case).

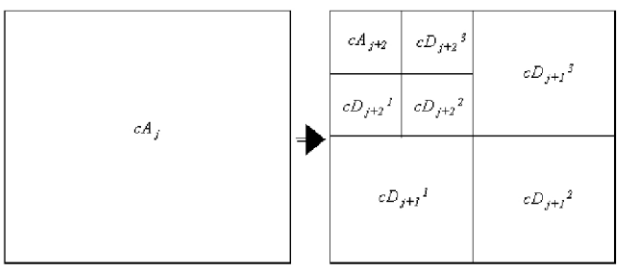

Figure3a: Level 2 decomposition of an image

All the approximations, cA_{j+1}, $1 < j < J$, can be obtained by repeating the process (where J is the maximum scale). cD_{j+1} denotes the difference of the input signal, also called the details at scale j. The detail cD_{j+1} is computed by convolving cAj with the high pass filter and returning every other sample of output. The performances of wavelet transforms of a discrete signal cAj can be obtained by successively decomposing cA_{j+1} into cA_{j+2} and cD_{j+2} for $0 <= j < J$. This representation provides information about approximation and details of signals at different scales. This multi-resolution analysis can be easily extended to two-dimensions by transforming in row and column directions separately. A wavelet transform of an image consists of four sub-images each with a quarter of the original area. The sub-image, composed of the low frequency parts for both row and column, is called an approximated image. The remaining three images, containing high frequency components, are termed detail images. This kind of two-dimensional wavelet transform leads to a decomposition of approximation coefficients at level j in four components- the approximation coefficients and the details in three orientations (horizontal, vertical, and diagonal) at level j+1. [2]

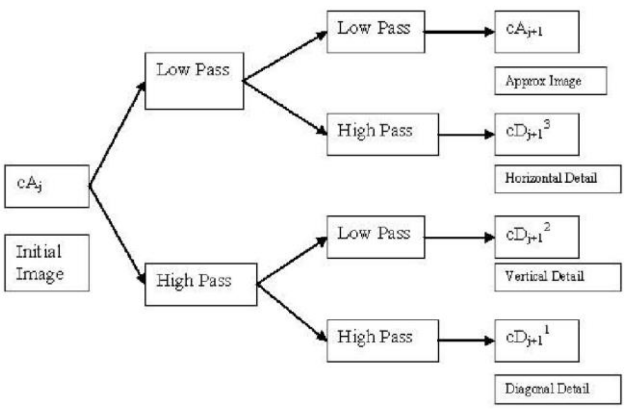

Figure3b: Level 1 decomposition of an image

2) Wavelet Coefficients

Wavelet transforms have proven to be an effective tool in the denoising. This possible due to fact that when wavelet transform is applied to an image, it is transformed into a compact set of coefficients which can further be used for easier computation.

Wavelet bases are bases of nested function spaces, which can be used to analyze signals at multiple scales. Wavelet coefficients contain both time and frequency information as the basis functions varies in position and scale. The coefficients can be obtained from the image by applying the Discrete Wavelet Transform where in the output of the low pass filter is the area of interest.

The method mainly consists of five steps: Normalisation, Wavelet Decomposition, Wavelet Coefficient Adjustment, Gabor filtering and Reconstruction.

a. Normalisation: As discussed in II A.
b. Wavelet Decomposition: The image is decomposed into multi resolution representation using wavelet transform. The convolution of the different base function with the input signal causes different effects in different resolutions. Theoretically, we can decompose the image into sub-images at any level. However, too low resolution is not suitable because an excessive down sampling of the signal can vanish the orientation characteristic of the ridge structure. Generally, only one or two decomposition levels are selected. The

benefit of this selection is not only in retaining the characteristic of the ridge structure to fit the filtering, but also speeds the computation. [1]

c. Wavelet Coefficient Adjustment: After decomposition, a series of wavelet coefficients are obtained each set of the wavelet coefficient corresponds to one resolution level on the dyadic scale. A non mapping function is used to apply gain to the set of wavelet coefficients. The gain applied to the coefficients affect the enhancement of image after inverse transform. Therefore gain must be applied only to the image coefficients and not the noise elements because this will result in enhanced noise visibility in the final image. A simple method would be to set a threshold value for the coefficient values and selectively increase the gain for the values above the threshold level and reduce the gain below that value.

d. Gabor Filtering: As mentioned earlier. The filtering is done on the sub image.

e. Reconstruction: After modifying the approximation sub-image with Gabor filters, the final image of the enhancement is reconstructed. Normally, the wavelets used in reconstruction are the same as that used in the decomposition process.[1]

III. Comparison of the Techniques

In a field like biometrics where the accuracy of the result is given more preference over anything else, it is of utmost importance that the new method that is developed need to be more accurate than the existing methods.

The first technique consists of implementation of 2D Fourier Transform for the enhancement stage. This is the computationally fastest method since it classifies the orientations to 16 directions. But this results in lesser accuracy since it assumes the frequency to be constant through out which is not the case.

In the second method the improvement is done by introduction of Gabor filters which takes into account both the frequency and orientation of the image and the filtering is done with a greater accuracy.

The Wavelet Transform has been found to be a very effective tool in denoising and compression techniques. Hence we use it in denoising part of the enhancement stage. It is computationally fast and effective compared to the present techniques of denoising of images.

In the third method the concept of wavelet transform is incorporated into it. The denoising stage is carried out with the help of wavelet transform. The image is decomposed to skeleton level and the denoising is done to this sub image which is comparatively faster than the prevalent algorithms. Moreover the translation of the images into mathematical terms increases the easiness to handle the image more effectively.

Hence a hybrid method was devised to improve the performance of enhancement techniques of fingerprint.

IV. Experimental results

The experimental results using the different methods of enhancement techniques are shown below. The images on the left of each of the figures (a) are the original finger prints and the ones shown on the right (b) are the enhanced images using respective algorithms.

(a) (b)

Figure 4: Fingerprint Enhancement using 2D Fourier Transform

(a) (b)

Figure 5: Fingerprint Enhancement using Gabor Filtering

(a) (b)

Figure 6: Fingerprint Enhancement using Wavelet Transform

Comparing the figures 4, 5 and 6 it is evident that with respect to the input image, the output enhanced image using the wavelet transform gives superior results

V. CONCLUSION

An efficient algorithm has been proposed for fingerprint enhancement. This incorporates the emerging technology of wavelets with Gabor Filters. Accordingly a new approach was devised for a clearer fingerprint image to be obtained, which can distinctly improve the accuracy of minutiae extraction module and finally achieve a better performance in the entire automatic fingerprint identification system.

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