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Fingerprint Image Enhancement Using Decimation-free Directional Filter Bank

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Abstract: The identification of fingerprint images mainly requires matching the features of the fingerprint in question with those stored in a database. Since fingerprint identification system may receive noisy and distorted fingerprint image inputs, an efficient and robust enhancement of fingerprint images is essential for reliable fingerprint identification. In this study, we propose a decimation-free directional filter bank (DFB) structure. It provides output in the form of directional images as opposed to directional sub-bands provided in previous DFBs. The presence of directional images facilitates any further spatial processing if needed. However, we have to prepare a fingerprint image before it can be given as input to the proposed DFB structure due to the fact that fingerprints acquired are low in contrast. The preparation steps involve removing non-uniform illumination from the image. Then proposed DFB structure outputs directional images. The final enhanced result is constructed on a block-by-block basis by comparing energy of all the directional images and picking one that provides maximum energy.

Key words: Directional Filter Bank (DFB), fingerprint image, directional images, illumination

INTRODUCTION

Directional analysis plays an important role in many areas and situations affecting actual life such as oil exploration, medicine, remote sensing and data analysis. There have been many proposed approaches for directional analysis in the past. The areas of applicability for this directional analysis cover almost all areas of 2-D and 3-D signal processing[1,2]. Here the focus is on fingerprint images.

A fingerprint is the pattern of ridges and furrows on the surface of the fingertip. Fingerprints have been used as a means to identify individuals uniquely for a very long time, having many various purposes such as criminal identification, high security access control, credit card usage verification and employee identification. The main reason for the popularity of fingerprints as a method of identification results forms the fact that each fingerprint of a person is unique as well as easy to access. The uniqueness of a fingerprint is exclusively determined by the local ridge characteristics and their relationships. Two most important ridge characteristics, called minutiae, are ridge ending and ridge bifurcation. Ridge ending is defined as a point where a ridge ends abruptly. A good quality fingerprint typically contains 40-100 minutiae. Examples of minutiae are shown in Fig. 1.

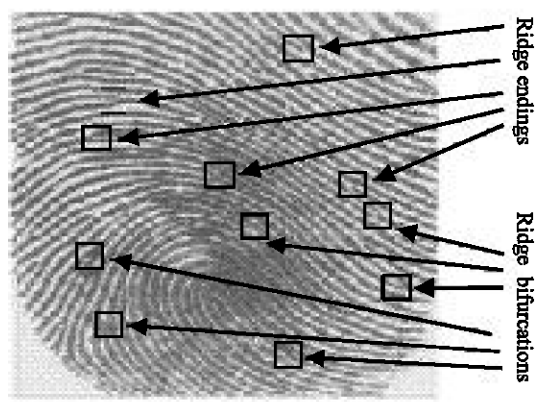

Fig. 1: Fingerprint image showing local ridge characteristics

Apart from minutiae identification and extraction, high-level features can also characterize a given class of the fingerprint. The important high-level features are the core and the delta points. Based on core and delta points fingerprint images can be classified into four different pattern classes. These classes include Arch, Tented Arch, Loop (left and right) and Whorl. Figure 2 provides some pictorial examples of high-level features.

Automatic fingerprint matching depends on the comparisons of either local ridge characteristics or the high level characteristics to make a personal identification.

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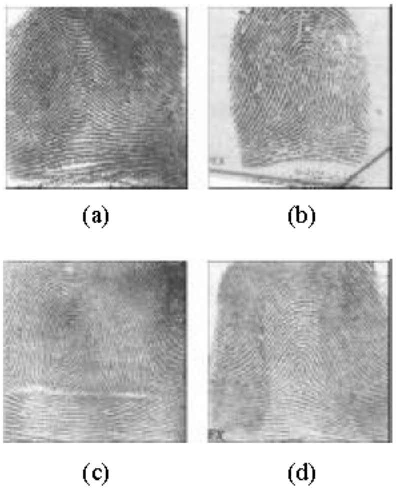

Fig. 2: High-level features of fingerprints (a) Arch, (b) Loop, (c) Whorl, (d) Tented arch

A critical step in fingerprint matching in both cases is to reliably extract features from the input fingerprint images. The performance of fingerprint identification mechanism relies heavily on the quality of the input fingerprint images. However, in practice due to variations in impression conditions, ridge configurations, skin conditions, acquisition devices and non-cooperative attitude of the subjects, a significant percentage of acquired fingerprint images are of poor quality. In order, to ensure that the performance of the identification algorithm will be robust with respect to the quality of the input digital fingerprint images, enhancement algorithms are needed which can improve the clarity of the ridge structure.

Various fingerprint enhancement techniques have been proposed in the literature. A fingerprint enhancement method based on directional Fourier domain filtering is presented[3], where direction of the pixel has been identified and then the image is being filtered and combined to get an enhanced image. The method was further improved[4], where direction calculation for a given pixel has been improved by using computationally efficient Gabor Filtering technique. However, the technique heavily depends on local direction finding mechanism which is prone to noise. An image analysis based on directional filter banks has been proposed and applied to fingerprint enhancement[5]. Later on, a visualizable directional filter bank[2] was used in correcting linear deformations in a given fingerprint image. Directional filter bank based fingerprint image enhancement was also proposed[6,7].

In this study, we proposed a new directional filter bank based fingerprint enhancement algorithm. The difference between the proposed algorithm and the previous techniques is the fact that we utilize directional images rather than directional sub-bands. The advantage of using directional images is that our enhancement works in the same domain as the images themselves. This helps us in using neighborhoods as compare to pixel by pixel approach used in previously suggested directional filter bank based techniques.

FINGERPRINT IMAGE ENHANCEMENT

A fingerprint image enhancement algorithm receives an input fingerprint image, applies a set of intermediate steps on the input image and finally outputs the enhanced image. The main steps of algorithms are as follows. The study with a test image shown in Fig. 3 and apply various processing steps sequentially.

Non-uniform illumination correction: An input fingerprint image has a varying illumination pattern that needs to be removed. Although, there are many spatial domain techniques available to get rid of non-uniform illumination structure. We opted for homomorphic filtering to extract non-uniform illumination of the input fingerprint image. An image a(x, y) can be expressed as a product of illumination and reflectance components i.e.

$$a(x, y) = i(x, y)\, r(x, y)$$

By taking the natural logarithm of input image a(x, y) in the spatial domain we have transformed the image into sum of its illumination and reflectance parts. This is shown in equation form as below:

$$z(x, y) = \ln\{i(x, y)\} + \ln\{r(x, y)\}$$

This is followed by taking discrete Fourier transform (DFT) of the logarithmic image. Now based on the fact that illumination is a slowly-varying pattern that will appear as low frequency content in the Fourier domain. Therefore, we applied a non-ideal butterworth

Fig. 3: Fingerprint test image

(a) (b)

Fig. 4: Illumination adjustment: (a) Non-uniformly illuminated image, (b) Uniformly illuminated image

lowpass filter to extract the lowpass region of the image. The transfer function of a butterworth lowpass filter of order n and with cut off frequency D_0 at a distance from the origin is defined as:

$$H(x,y) = \frac{1}{1 + [D(x,y)/D_0]^{2n}}$$

where, D (x, y)is a radial distance from the origin. After filtering the image and inverse DFT has been applied to transform the filtered image from Fourier domain back to spatial domain. Finally, illumination pattern present in an image can be obtained by taking exponential of the resulting output in the spatial domain. The extracted illumination pattern can be subtracted from the test image to obtain a uniformly illuminated image as shown in Fig. 4. In our test image case, we employed as and order of the butterworth filter n was 2.

CREATION OF DIRECTIONAL IMAGES

This section has been divided into two sections.

Design of directional filters: The directional analysis employed in this study decomposes the spectral region of a given image into wedge-shaped passband regions. It is easily shown that these wedge-shaped regions correspond to directional components of an image. The filters related to these wedge-shaped regions are commonly referred to as fan filters.

The schematic diagram of proposed structure is shown in Fig. 5. The structure is in the form of a tree with two-band splits at the end of each stage, where each split increases the angular resolution by the factor of two. The first stage employs the complimentary hour-glass filters. The filters for next two stages are obtained by linear transformation of the first stage hour-glass filters. For implementing linear transformation, the uni-modular matrices M and R are utilized. The rules for the selection of these matrices are presented[2]. Once the filters for each stage are implemented, we can combine them on branch by branch basis to get the required fan filters as shown at the end of third stage in Fig. 5.

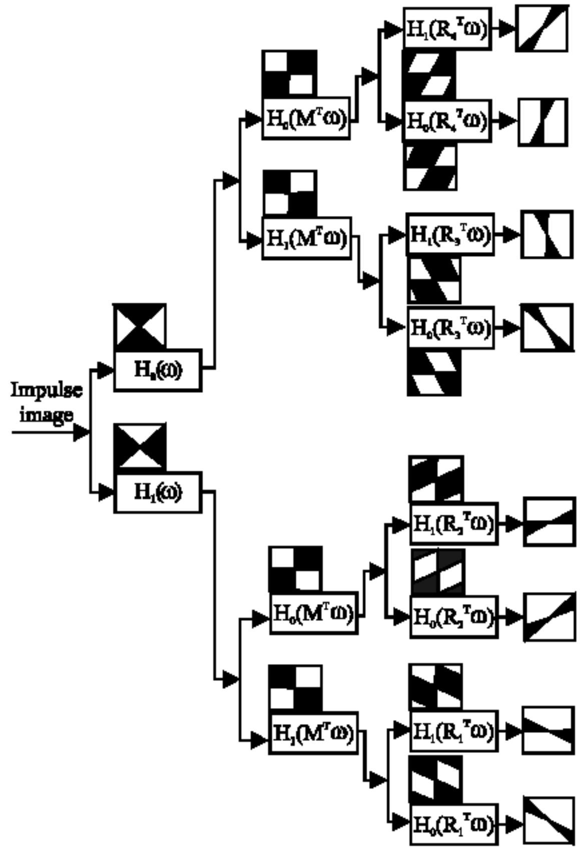

Fig. 5: Directional filter bank schematic diagram

One important difference between present proposed structure and DFB structure[2], is the absence of decimator. It was pointed out[5] that if sub-bands need to be processed for directional energy estimates, the decimation present in the conventional filter bank structure poses problem. This means that two samples located at the same spatial index (n_1, n_2) in two different sub-bands i and j, will not necessarily correspond to same spatial region in the original image. This problem was circumvented[5] by employing nearest-neighborhood or bilinear interpolation to make all sub-bands of the same size. However, in our structure, decimators at each stage are taken out and filters are designed by linear transformation in the frequency domain to get fan filters. Furthermore, to avoid ringing artifact in the output, ideal fan filters are avoided by employing non-ideal hour-glass filters using an FIR lowpass filter[8].

Directional images: Directional images are obtained by applying all directional filters constructed in above section. Four of these directional images are shown in Fig. 6. These directional images can be regarded as decomposition of the original image in eight pieces based

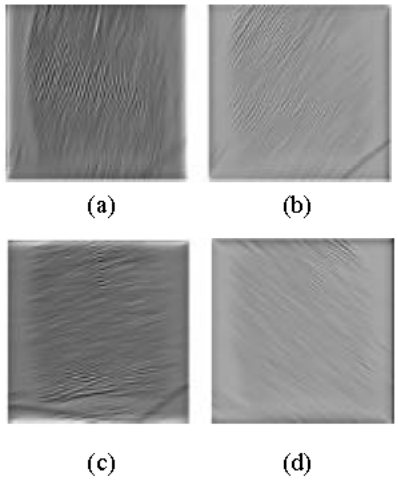

Fig. 6: Creation of directional image; (a) Ridges having direction in the range 67.5-90 degrees, (b) Ridges having direction in the range 45-67.5 degrees, (c) Ridges having direction in the range 0-22.5 degrees, (d) Ridges having direction in the range 135-157.5 degrees

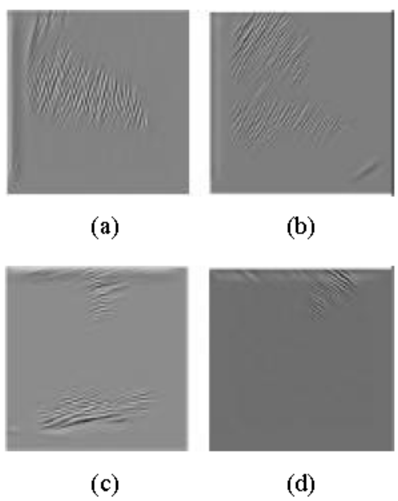

Fig. 7: Creation of noise-free images: (a) Noise-free image of Fig. 6a, (b) Noise-free image of Fig. 6b, (c) Noise-free image of Fig. 6c, (d) Noise-free image of Fig. 6d

on direction. Directional images contain features associated with global directions rather than local directions. By creating directional images we have divided noise of the original image into eight different directions.

Noise removal: Noise removal is accomplished by first calculating the block based directional energy of each directional image. The directional energy of a block (X, Y) including the pixel (x, y) from the kth directional image is calculated as:

Fig. 8: Enhanced result

Fig. 9: Binarization of original image

$$E_k(X,Y) = \sum_{x=0}^{m_k} \sum_{y=0}^{n_k} \left| f_k(X,Y;x,y) \right|$$

where, f_k is the directional image. The noise free directional images represented by A_k are obtained by the equation.

$$A_k = \begin{cases} f_k(X,Y;x,y) & \text{if } E_k(X,Y) > T \\ f_k(X,Y;x,y) & \text{if otherwise} \end{cases}$$

Here, T represents the threshold. Figure 7 shows four of eight noise free directional images. Comparing these images with Fig. 8 shows that noise has been cleaned where as features are preserved.

Reconstruction of enhanced image: Enhanced image is constructed from the directional images according to the following equation:

$$f_{hf}(X,Y) = \max_{1 \le i \le 8} f_i(X,Y),$$

Where, f_{hf} is high-frequency output image from directional filter bank and f_I represents ith directional image. For

Fig. 10: Binarization of enhanced image

every block (X, Y) of the original image we select a replacement from the eight directional images based on maximum directional energy. The final enhanced fingerprint image obtained is shown in Fig. 8. Comparing the result with the original image shown in Fig. 3 reveals that all the ridge structure is intact while the spatial noise has been cleaned substantially. Figure 9 and 10 show the results of binarization of the original image and that of the enhanced image, respectively. Enhanced fingerprint image results in a binary image with clear ridges and valleys.

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