Fingerprint Image Enhancement Using Decimation Free Directional Adaptive Mean Filtering

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Abstract. In this paper we proposed a new enhancement technique that is based on the integration of Decimation Free Directional responses of the Decimation Free Directional Filter Banks (DDFB), adaptive mean filtering and the eigen decomposition of the Hessian matrix. By decomposing the input fingerprint image into decimation free directional images, it is easy to remove the noise directionally by means of adaptive mean filtering and further eigen decomposition of the Hessian matrix was used for the segmentation purpose. As the input fingerprint image is not uniformly illuminated so we have used the bandpass filter for the elimination of non-uniform illumination and for the creation of frequency ridge image before giving it to DDFB. 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.

1 Introduction

Fingerprint is the first biometric system adopted by law enforcement agencies, and now is also the most widely used system. A fingerprint is believed to be unique to each person. Fingerprints of even identical twins are different thats why they have gained so much popularity for the identification purpose. Any fingerprint identification system highly depends on the quality of the fingerprint image. As the fingerprint images are corrupted by different kinds of noise so the need of enhancement is always there. Several techniques have been proposed in the literature for fingerprint image enhancement but there is still need of improvement.

Researchers in recent years have used different methods for the enhancement of the fingerprint. In a recent study[1] fingerprint enhancement, feature extraction and matching [2] has been proposed using directional filter banks. One most

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commonly used directional filter for fingerprint enhancement and matching is a Gabor filter [3,4]. They have both frequency-selective and orientation-selective properties and have optimal joint resolution in both spatial and frequency domains. They have been used in [5], where the gradient direction of the pixels have been identified and then the image is being filtered according to the gradient direction and combined to get an enhanced image. The use of the second directional derivatives has been proposed in [6] where the positive second directional derivative was used to detect the ridges in the image.

In this paper we have used DDFB for the directional analysis of the input image and then adaptive mean filtering was used for the noise removal. After applying adaptive mean filtering on each of the directional image as an output of DDFB, the eigen decomposition of the Hessian matrix was computed at each image pixel. Rest of the paper is organized as follows: in Section II, the proposed system is discussed whereas reconstruction of the enhanced image, some of the experimental results and a comparison is presented in Section III.

2 Fingerprint Image Enhancement

The proposed system takes the fingerprint as an input for the enhancement as shown in Fig. 1. The main steps involved in the proposed system are described below in a sequential order.

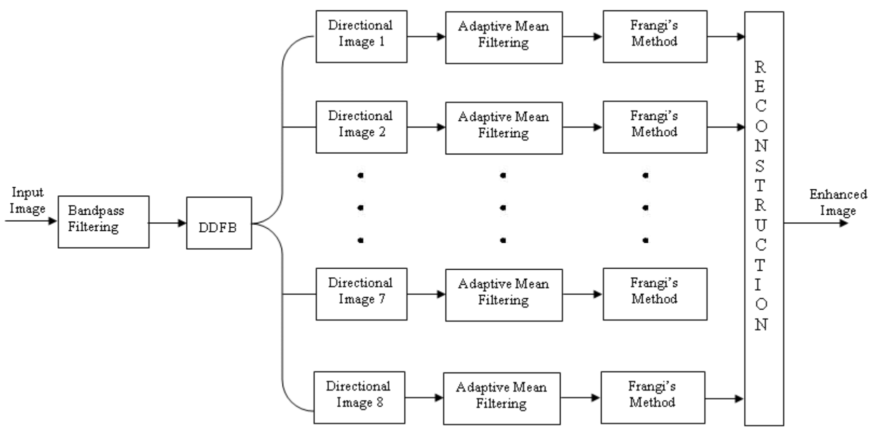


Fig. 1. Proposed Fingerprint Image Enhancement System

2.1 Illumination Adjustment and Creation of Ridge Frequency Image

The fingerprint can be approximated by a two-dimensional sinusoidal of different orientations as proposed in [7,5]. It is shown in Fig. 3, that a periodic sinusoid of a particular orientation in the spatial domain is represented by two points in

Fig. 2. Fingerprint Test Image

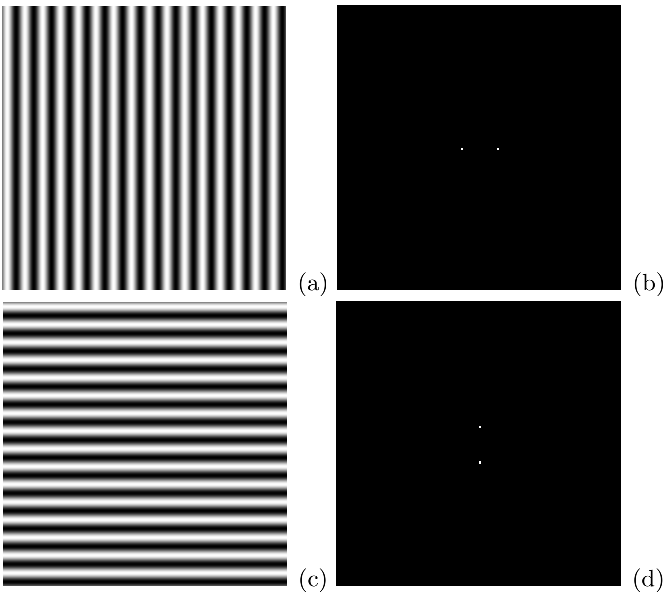


Fig. 3. a,c) Periodic Sinusoidal of a particular direction in Spatial Domain b,d) Periodic Sinusoidal represented by two points in frequency Domain

the frequency domain. As the fingerprint image is a two dimensional sinusoids of different orientations, so the ridge frequencies are represented by the points in a circular region in the frequency domain as show in in Fig. 4. As we are interested in the enhancement of the ridges only rather than the background, we have used the bandpass filter whose passband allows the ridge frequencies represented by the circular region in the frequency domain to pass through it. The bandpass filter not only allows us to have a ridge frequency image but also helps in the removal of non-uniform illumination. As the non-uniform illumination is present as low frequency content in the frequency domain, so we have applied the non-ideal butterworth bandpass filter. It is filtered out by the lower stop-band region

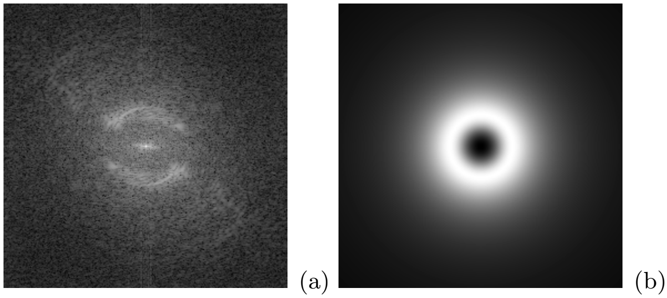


Fig. 4. a) Representation of image in Frequency Domain. b) Frequency Response of Bandpass Filter.

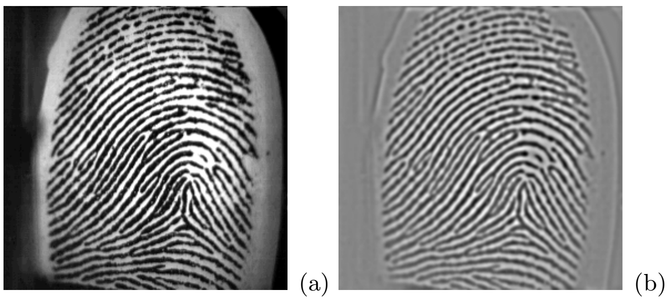


Fig. 5. Illumination Adjustment: a) Non-uniformly illuminated image. b) Simply processed to eliminate the effects of non-uniform illumination and having ridge frequencies only.

of the bandpass filter. High frequency noise is treated by the upper stop-band region of the bandpass filter. The equation of the bandpass filter is given below

$$H(u,v) = \begin{cases} 1 \text{ if } D(u,v) < D_0 - \frac{W}{2} \\ 0 \text{ if } D_0 - \frac{W}{2} \leq D(u,v) \leq D_0 + \frac{W}{2} \\ 1 \text{ if } D(u,v) > D_0 + \frac{W}{2} \end{cases} \tag{1}$$

where $D(u,v)$ is a radial distance from the origin., W is the width of the band, and D_0 is the radial center. The bandpass filter was applied by taking the discrete fourier transform (DFT) of the input image as shown in Fig. 4. After filtering the image, inverse DFT has been applied to transform the filtered image from fourier domain back to spatial domain. Finally we got a uniformly illuminated image having the ridge frequencies only as shown in Fig. 5. One important benefit of using bandpass fltering is that the segmentation of Fig. 5.b in order to find the fingerprint area is easier as compared to the original image and we can use the local variance to segment the image. We used the bandpass filter whose pass-band is designed in such a way that only the ridge frequencies can pass through it as shown in Fig. 4.

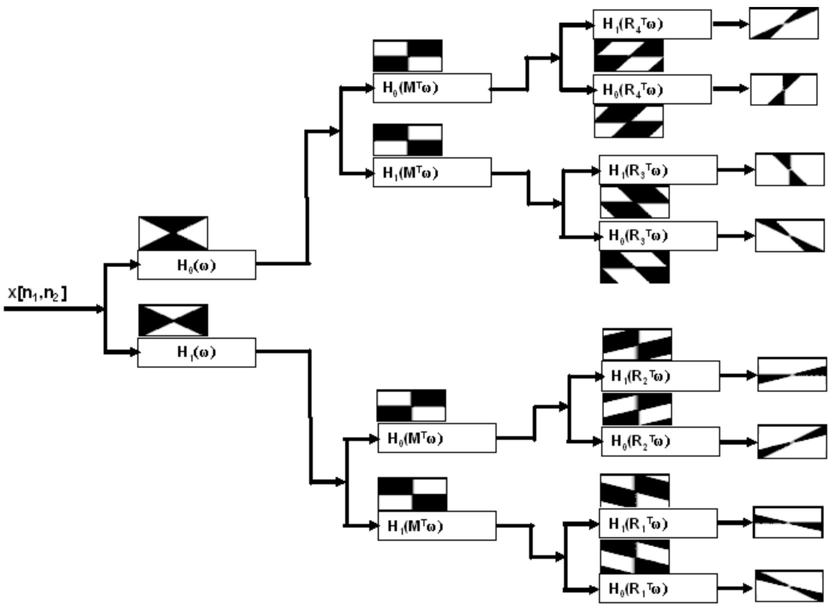


Fig. 6. Schematic Diagram of DDFB

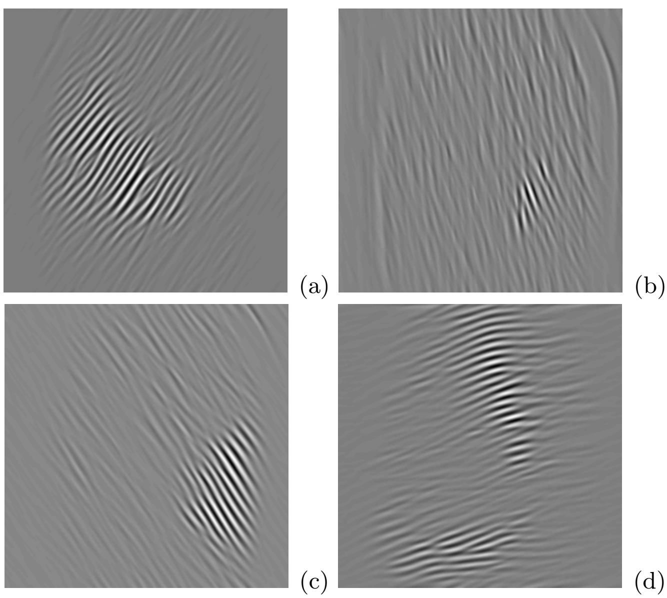


Fig. 7. Four out of eight Directional Images

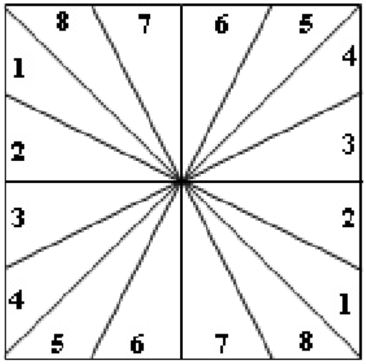


Fig. 8. Frequency partition map for 8-band DFB

2.2 Creation of Decimation-Free Directional Images

We have used the Decimation Free Directional Filter Banks (DDFB) for the directional analysis of the input image as proposed in [1]. The reason for using the DDFB rather than the Directional Filter banks(DFB), is that the output of the DDFB is of the same size as of the input image, so we can avoid extra step of interpolation which was required for the output of DFB for the enhancement purpose. DDFB decomposes the spectral region of the input image into wedge-shaped passband regions shown in Fig. 8. It is easily shown that these wedge-shaped regions correspond to directional components of an image. The filters related to wedge-shaped regions are commonly referred to as fan filters [8]. The block diagram of DDFB structure is shown in Fig. 6. Four out of eight directional images are shown in Fig. 7.

2.3 Noise Removal Using Adaptive Mean Filtering

We have used the adaptive mean filtering [9] for the removal of the gaussian noise in each of the eight directional outputs of the DDFB as shown in Fig. 9. As noise is a random variable, so it can be measured statistically by using its mean and variance which are closely related to the appearance of an image. The average gray level is represented by the mean in the local region S_{xy} over which it is computed, and variance gives the measure of average contrast in that local region S_{xy}. The equation of adaptive mean filter is given below

$$output = g(x,y) - \frac{\sigma_\eta^2}{\sigma_L^2}[g(x,y) - m_L], \tag{2}$$

Our filter operates locally in a region, S_{xy}. The response of the filter at any point (x, y) on which the region is centered is to be based on four quantities:

1. $g(x, y)$, the value of the noisy image at (x,y).

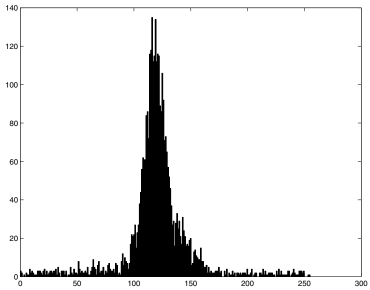


Fig. 9. Noise represented by Gaussian Distribution

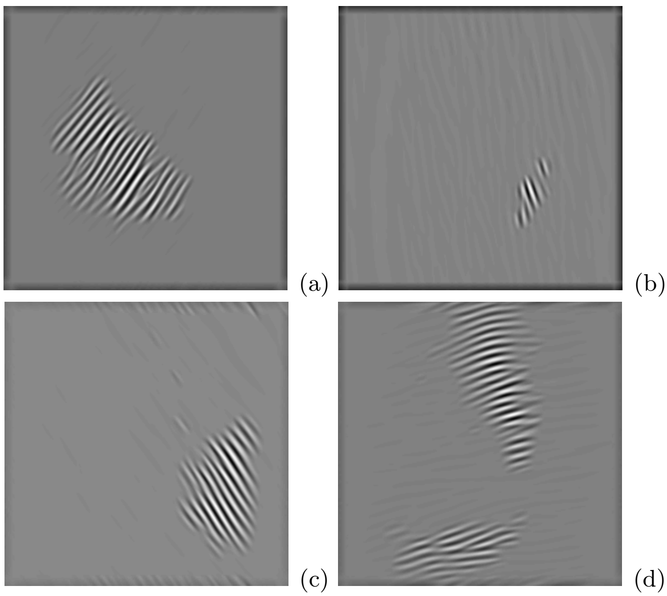


Fig. 10. Creation of noise-free images: (a) Noise-free image of Fig. 7. a, (b) Noise-free image of Fig. 7 b, (c) Noise-free image of Fig. 7. c, (d) Noise-free image of Fig. 7. d

2. σ_η^2, the variance of the noise corrupting f(x,y) to form g(x,y)) and can be calculated as

$$\sigma_\eta^2 = \sum_{z_i \varepsilon S_{xy}} (z_i - \mu_\eta)^2 p(z_i) \tag{3}$$

μ can be calculated as

$$\mu_\eta = \sum_{z_i \varepsilon S_{xy}} (z_i) p(z_i) \tag{4}$$

3. m_L, the local mean of the pixels in S_{xy}.
4. σ_L^2, the local variance of the pixels in S_{xy}.

where z_i is the value of the gray level in S_{xy} and $p(z_i)$ is the probability of each gray level in S_{xy}. The results after applying the adaptive mean filtering is shown in Fig. 10. It can be seen that the filter has removed the noise directionally.

2.4 Segmentation of Decimation Free Directional Images

In this section, noise-free images obtained as an output of DDFB are segmented in a way that whole ridge structure can easily be discriminated from the background.

In recent years there has been a fair amount of research on fingerprint and vessel enhancement. One popular way is to use eigen decomposition of the Hessian computed at each image pixel [10], [11], [12], [13], [14]. We proved that this enhancement which was initially used for detecting blood vessels in the medical images can be successfully used to enhance ridges. Eigenvalues are used in rules to decide if a particular location is a ridge pixel or not. When a pixel passes this test, the eigenvector corresponding to the smaller (in absolute value) eigenvalue points along the vessel. The signs of the eigenvalues determine bright or dark structures. Vesselness measures are defined in [11]and [12]. Frangi et al. [11]

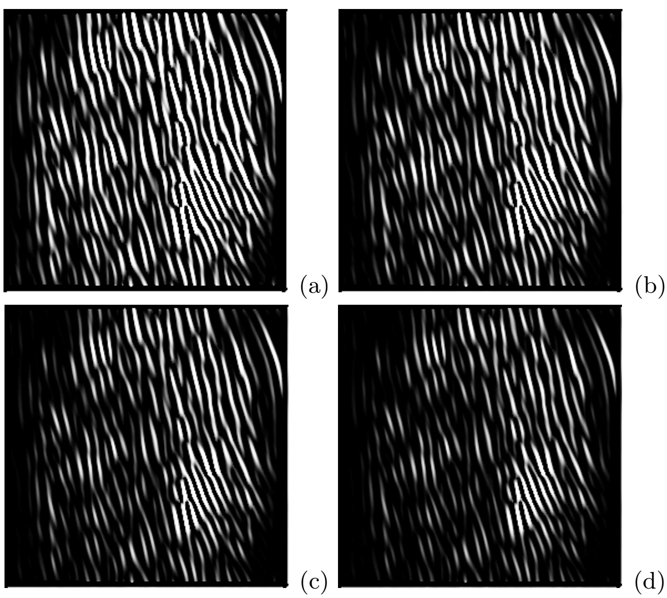


Fig. 11. Results obtained by applying Frangi's method on Fig. 7 at different values of β_2 but at constant β_1. (a) Segmented image of Fig. 10. b with $\beta_1 = 2$ and $\beta_2 = 4$, (b) Segmented image of Fig. 10 b with $\beta_1 = 2$ and $\beta_2 = 6$, (c) Segmented image of Fig. 10. b with $\beta_1 = 2$ and $\beta_2 = 8$. (d) Segmented image of Fig. 10. b with $\beta_1 = 2$ and $\beta_2 = 10$.It is clear from all the results that by increasing the value of β_2 we have managed to reduce noise but on expense of low-contrast ridges which also diminished along with noise. Where β_1 and β_2 are thresholds which control the sensitivity of the measures R_A and R_B.

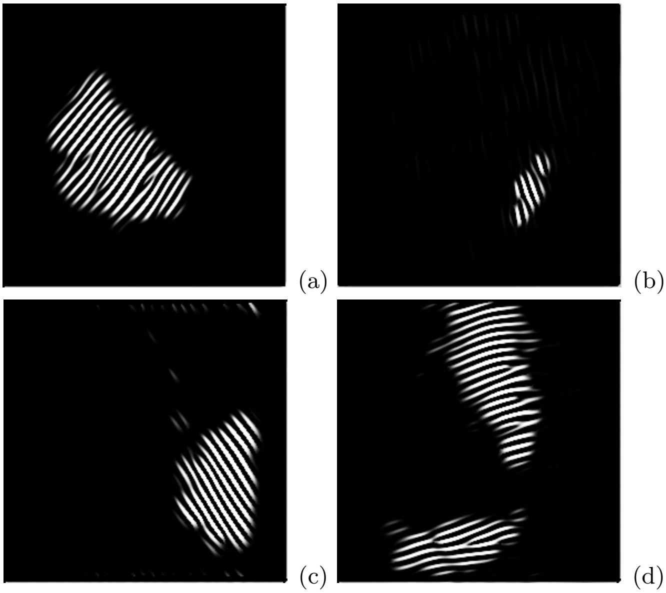


Fig. 12. (a) Segmented image of Fig. 10. a, (b) Segmented image of Fig. 10 b, (c) Segmented image of Fig. 10. c, (d) Segmented image of Fig. 10. d.

proposed using ratios of the eigenvalues $|\lambda_1| \leq |\lambda_2| \leq |\lambda_3|$ to determine scores $R_B = |\lambda|/|\lambda_2\lambda_3|$ and $R_A = |\lambda_2|/|\lambda_3|$ and computing the Frobenius norm, S, of Hessian to measure overall strength. For tube-like structures, including vessels, R_B should be low and R_A should be high. Since there is an involvement of second order derivatives the presence of noise is significant. For eliminating noise Frangi et. al. introduce parameters. We have employed the Frangi's method on the directional images obtained as an output of the previous step as shown in Fig. 12. We also implemented the Frangi's method direct to the input image as shown in Fig. 11, it is clear from the Fig. 11 that for the fingerprint image enhancement we cant use the Frangi's method directly, we need to remove the noise directionally, so we can say that the noise present in the fingerprint image was a directional noise which needs to be removed directionally by means of adaptive mean filtering.

3 Reconstruction of Enhanced Image

We have used directional energy of the cleaned directional images for construction of enhanced image. In DDFB we can compare energy estimates for samples which correspond to the same spatial regions due to the same size of directional images. Overlapping block-by-block directional energy is computed for each directional image by using the formula given below:

$$D^{i}_{energy}(x, y) = \Sigma(\Sigma(|D^{i}_{image}(x : x + B(1), y : y + B(2)) - m_B|)), \quad (5)$$

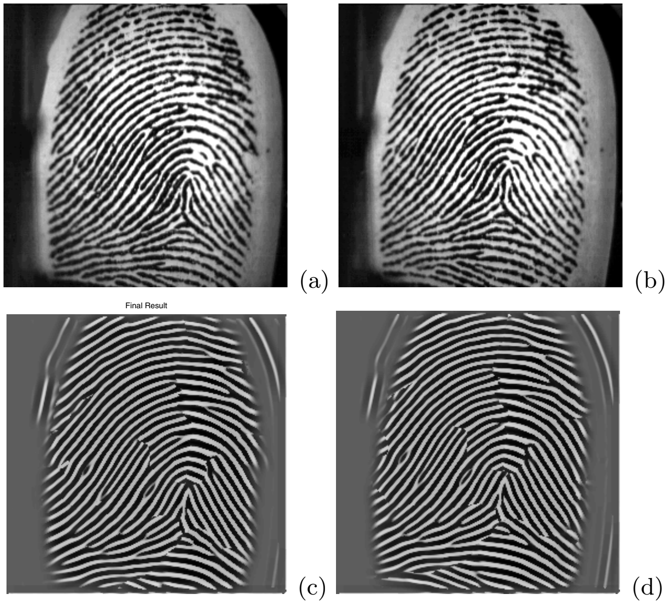


Fig. 13. (a),(b) Images of the same subject from the FVC2002 Database.(c),(d) Enhanced Images of (a),(b).

where B is a vector which defines the block size $B(1) \times B(2)$ for which the energy is to be calculated, and (x, y) represents pixel positions in an integer image lattice. $D^i_{image}(x : x+B(1), y : y+B(2))$ represents block from directional image i and m_B represents the mean of that block. Here m_B is subtracted from each block to remove the effect of local non-uniform illumination. In this manner we will have eight directional energy images D^i_{energy} $(i = 1, 2, 3, 4, 5, 6, 7, 8)$, where each directional energy image correspond to one of the eight directional images.

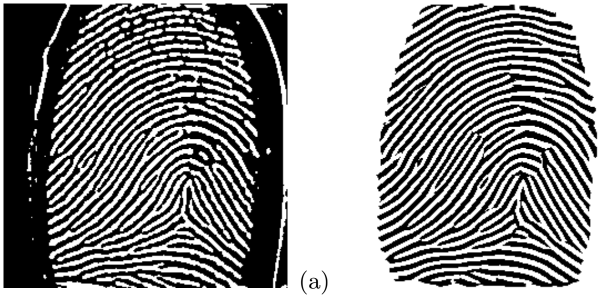
Energy equation used in this paper gives the rate of change among pixel values. Enhanced image H_{enh} can be constructed from the directional energy images by using following steps.

1. For each pixel (x, y) find the energy image having maximum directional energy. For example, for pixel position (x, y), we would find maximum $(max(D^i_{energy}(x, y)))$ in all D^i_{energy} images. Here (x, y) are pixel positions in an image lattice. Mathematically we can say that,

$$[m, ind] = max(D^i_{energy}(x, y)) \tag{6}$$

   where i = 1,2,3,4,5,6,7,8.

where m is the value of maximum energy for a particular pixel position (x, y) and ind is the index of D_{energy} image from which pixel (x, y) is declared as maximum. After calculating maximum energy for each pixel we form a new image E_{image} having only maximum energies. This E_{image} is the final enhanced fingerprint.



(a) (b)

Fig. 14. (a) Result of Binarization of original image. (b) Result of Binarization of enhanced image.

The final enhanced fingerprint image E_{image} obtained is shown in Fig. 13c. Comparing the result with the original image shown in Fig. 2 reveals that all the ridge structure is intact while the spatial noise has been cleaned substantially. Fig. 14 show the results of binarization of the original image and that of the enhanced image respectively. We see that enhanced fingerprint image results in a binary image with clear ridges and valleys. The quality of the fingerprint image enhancement system depends on how it enhances the fingerprint images of the same person. We have tested our proposed approach on the fingerprint images from FVC2002 and the comparison between Fig. 13c,d with the images shown in Fig. 13a,b reveals that the proposed system has enhanced both the images in the same manner which is the requirement of any fingerprint recognizing system for the identification.

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