Performance Analysis and Designing of Fingerprints Enhancement Technique Based on Segmentation, OF Estimation and Ridge Frequency, Gabor Filters with Wavelet Transform

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Abstract - **The objective of image enhancement technique is to improve the overall performance by optimally arranging input images for afterward processing stages. A fingerprint is the pattern of ridges and valleys on the surface of a fingertip. Each person has unique fingerprints. The uniqueness of a fingerprint is exclusively determined by the local ridge characteristics and their relationships. 150 different local ridge distinctiveness like islands, short ridges, enclosure, etc. have been acknowledged. These local ridge distinctiveness are not evenly distributed. Most of them heavily depends on the impression conditions, quality of fingerprints and are not often observed in fingerprints. The two most prominent local ridge characteristics, called minutiae, are ridge ending and ridge bifurcation. A ridge ending can be defined as the point where a ridge ends sharply. A ridge bifurcation is defined as the point where a ridge forks or diverges into branch ridges. A good quality fingerprint characteristically contains approximately 40–100 minutiae. Therefore, how to appropriately extract minutiae from fingerprint images becomes an important step in fingerprint identification. Most systems extract minutiae from fingerprints and the presence of noise can interfere with the extraction of minutiae. As a result, true minutiae may possibly be missed, and false minutiae possibly will be detected and both of these have a negative effect. In order to avoid these two types of errors, image enhancement plans at improving the clarity of the ridge and valley structures. To achieve good minutiae, initially, extraction is done in fingerprints with varying quality, then preprocessing in form of image enhancement. Many methods have been joined to build a minutia extractor and a minutia matcher. The goal of this dissertation is to design 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, is be implemented in this dissertation work. Performance of the new developed system is then evaluated using visual analysis and goodness index value of enhanced image**.

Keywords: **Biometrics, fingerprint, minutiae, enhancement, Gabor filters (GFs), segmentation, histogram equalization, fingerprint recognition, FVC2004, image enhancement, orientation-field (OF) estimation, ridge frequency (RF) estimation, verification tests.**

1. INTRODUCTION

1.1 Fingerprint: Fingerprints are the patterns formed on the epidermis of the fingertip. Skin on human fingertips contains ridges and valleys which together forms distinctive patterns. A fingerprint is comprised of ridges and valleys. The ridges are shown in the dark area of the fingerprint and the valleys are shown in the white area that exists between the ridges. A ridge is defined as the single curved segment, and valley lies between the two adjacent ridges. These patterns are fully developed under pregnancy and are permanent throughout whole lifetime. Prints of those patterns are called fingerprints. The interleaved pattern of ridges and valleys are the most evident structural characteristic of a fingerprint. Three main fingerprint features are:

a) Global Ridge Pattern
b) Local Ridge Detail
c) Intra Ridge Detail

1.2 Fingerprint Enhancement: A critical step in Automatic Fingerprint matching system is to automatically and reliably extract minutiae from input finger print images. However the performance of the Minutiae extraction algorithm and other fingerprint recognition techniques relies heavily on the quality of the input fingerprint image. In an ideal fingerprint image, ridges of fingerprint and valleys of fingerprint alternate and flow in a constant direction. However the fingerprint images obtained are usually poor due to elements that corrode the clarity of the ridge elements. This leads to issues in minutiae extraction. Thus, image enhancement techniques are employed to reduce the noise and enhance the definition of ridges against valleys. In order to ensure good performance of the ridge and minutiae extraction algorithms in poor quality fingerprint images of database, an enhancement algorithm is applied to improve the clarity of the ridge structure is necessary [5].

A fingerprint image contains regions of different quality. Fingerprint images have:

a) Well-defined region
b) Recoverable region
c) Unrecoverable region.

Well-defined regions, recoverable regions and unrecoverable regions may be identified according to image contrast, orientation field consistency, ridge frequency of image, and other local features of fingerprint image.[8] The ridge structures in poor-quality fingerprint images are not always well-defined and, hence, they can be incorrectly detected. This leads to following issues:

1) A significant number of spurious minutiae in image may be created,

2) A large percent of genuine minutiae may be ignored, and 3) Large errors in their localization (position and orientation) may be introduced in fingerprint image [9].
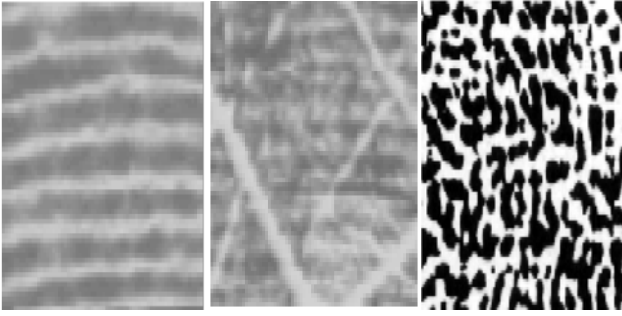

Fig:1 Fingerprint regions (a) Well-defined region. (b) Recoverable corrupted region (c) Unrecoverable corrupted region [9]

In order to ensure that the performance of the minutiae extraction algorithm will be robust with respect to the quality of input images, an enhancement algorithm can improve the clarity of the ridge structures. A fingerprint expert is often able to correctly identify the true minutiae by using various visual clues such as local ridge orientation of image, ridge continuity, ridge tendency, etc., as long as the ridge and valley structures are not corrupted completely. The goal of an enhancement algorithm is to improve the clarity of the ridge structures in the recoverable regions and mark the unrecoverable regions as too noisy for further processing. The input of the enhancement algorithm is a gray-scale image. The output may either be a gray-scale or a binary image. In order to ensure to extract the true minutiae points it is essential to incorporate the enhancement algorithm. There are two ways in which we can enhance the input fingerprint image.
1. Binarization method. 2. Direct gray-level enhancement.

2. ENHANCEMENT USING GABOR FILTER

One of the most widely cited fingerprint enhancement techniques is the method employed by Hong et al., which is based on the convolution of the image with Gabor filters tuned to the local ridge orientation and ridge frequency. This algorithm includes normalization, ridge orientation field estimation, frequency estimation of ridge and filtering [5, 28]. The first step in this approach involves the normalization of the fingerprint image so that it has a pre-specified mean and variance. Due to fault in the fingerprint image capture process such as non-uniform ink intensity or non-uniform contact with the fingerprint capture device, a fingerprint image may exhibit distorted levels of variation in grey-level values along the ridges and valleys [5]. Thus, normalization is used to reduce the effect of these variations, which facilitates the subsequent image enhancement steps. Orientation field estimation is then calculated, which is a matrix of direction vectors representing the ridge orientation at each pixel in the image. The widely employed gradient-based approach is used to calculate the gradient, which makes use of the fact that the orientation vector is orthogonal to the gradient. The next step in the image enhancement process is the estimation of the ridge frequency image. The frequency image defines the local frequency of the ridges contained in the fingerprint.

Firstly, the image is divided into square blocks and an oriented window is calculated for each block. For each block, an x-signature signal is constructed using the ridges and valleys in the oriented window. The x-signature is the projection of all the grey level values in the oriented window along a direction orthogonal to the ridge orientation. Consequently, the projection forms a sinusoidal-shape wave in which the centre of a ridge maps itself as a local minimum in the projected wave. The distance between consecutive peaks in the x-signature can then be used to estimate the frequency of the ridges.

Fingerprint enhancement methods based on the Gabor filter have been widely used to facilitate various fingerprint applications such as fingerprint matching and fingerprint classification. Gabor filters are band pass filters which have frequency-selective and orientation-selective properties both, which mean the filters can be effectively tuned to specific frequency and orientation values. One important characteristic of fingerprints image is that they are known to have well defined local ridge orientation and ridge frequency. Therefore, the enhancement algorithm takes advantage of this regularity of spatial structure by applying Gabor filters that are tuned to match the local ridge orientation and frequency. Based on the local orientation and ridge frequency around each pixel in image, the Gabor filter is appeal to each pixel location in the image. So the filter enhances the ridges oriented in the direction of the local orientation, and decreases anything oriented differently in fingerprint image. Hence, the filter is used to increases the contrast between the foreground ridges and the background in image and perfectly reduce noise in image [16-18].

Lastly, local adaptive threshold is applied to the directionally filtered image, which produces the enhanced binary image. This involves calculating the average values of the grey-level within defined window at each pixel in image, and if the average value is greater than the threshold, then the pixel value is set to one value; otherwise, it is set to zero value. The grey-level image is converted into a binary image in which only two levels of interest are the foreground ridges and the background valleys [20, 22].

3. STEPS OF METHODOLOGY

Problem Definition: The fingerprint is enhanced by clarity the structure of ridge and valley in fingerprint image.

The objectives are

A) Gabor filter is used to improve the quality of fingerprint image by removing spurious minutiae.

B) Binarization is performed using threshold.

C) Minutiae are extracted.

Assumptions:

    a) FVC2004 databases of fingerprint are taken.

Algorithm of proposed methodology

- Input: Fingerprint Image
- Output: Enhanced True Minutiae From Input Image.
1) Fingerprint Enhancement is used to increase the low quality to high quality image.
2) Gray scale value is used to convert gray scale image to binary image using Binarization.
3) Histogram equalization is a process which is used to enhance the contrast of images by transforming its intensity values.
4) Normalization allows standardizing the distorted levels of variation in the gray scale values among ridges and valleys by assigning prespecified standard mean and variance values.
5) Renormalization is applied to again normalize the normalized image by standardize the remaining distorted levels of variation in the gray scale values among ridges and valley.
6) Segmentation is the approach of separating the foreground regions in the image from the background regions where the foreground regions correspond to the clear fingerprint image area containing the ridges and valleys, which is the area of interest and the background corresponds to the regions outer the borders of the fingerprint area, which do not contain useful fingerprint information.
7) The orientation field of a fingerprint image defines the local orientation of the ridges contained in the fingerprint. Local ridge orientation is estimated at each point by finding the principal axis of variation in the image gradients.
8) In ridge frequency estimation, the frequency image represents the local frequency of the ridges in a fingerprint. Window size, block size, min. and max. wavelength parameters is initiazed for estimation of ridge frequency.
9) Gabor filter is applied to filter the fingerprint image by assigning two parameters i.e. bandwidth control and orientation. After applying Gabor filter we get enhanced fingerprint which has fine quality of true minutiae.

    Wavelet transform is used to denoising the image and increases the contrast between the ridge and background by using a map function to the wavelet coefficient set.
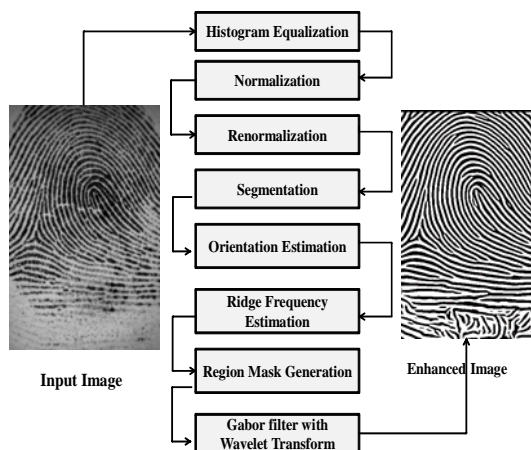10) Lastly we perform binarization of new enhanced image.

Fig.2 Flow Chart of methodology

3.1 HISTOGRAM EQUALIZATION

Histogram equalization is a process which is used to enhance the contrast of images by transforming its intensity values. Usually each fingerprint image has different gray values for every pixel. It is desirable to have the gray value around a mean value. This is achieved by histogram equalization which increases the local contrast of images. Thus the intensities can be distributed on the histogram. This process allows for areas of lower local contrast to gain a higher contrast without affecting the global contrast. Histogram equalization achieves this by effectively spreading out the intensity values. The histogram of the original image explains that all the intensity values lie on the right hand side of the 0–255 scale with no pixel in the left hand side. The histogram of the normalized image allows that the range of intensity values has been adjusted such that there is a more balanced distribution between the dark and light pixels.

Normalized image improves the contrast between the ridges and valleys. It does not modify the shape of the original histogram plot. The relative position of the values along the x axis is shifted. Histogram equalization is a technique for adjusting image intensities to enhance contrast, basically Histogram equalization give us transform image where the intensity value having uniform distribution and because of this process image we get appear to be high contrast Histogram Equalization defines a mapping of gray level p into gray level q such that the distribution of gray level q is uniform. This mapping spreads the contrast of gray level near the maxima in the histogram [10]. The probability density function of a pixel intensity level r_k is yield by formula:

$$P_r\left(r_k\right) = \frac{n_k}{n} \tag{1}$$

Where r_k is between 0 and 1, k=0, 1.....255, n_k is the number of pixels at intensity level r_k and n is the total number of pixels. The new intensity value S_k for level k is derived by formula:

$$S_k = \sum_{j=0}^{k} \frac{n_k}{n} = \sum_{j=0}^{k} P_r\left(r_j\right) \tag{2}$$

3.2 SEGMENTATION

After Histogram Equalization, the next step of the fingerprint enhancement algorithm is image segmentation. Segmentation is the approach of separating the foreground regions in the image from the background regions. The foreground regions correspond to the clear fingerprint image area containing the ridges and valleys, which is the area of interest. The background corresponds to the regions outer the borders of the fingerprint area, which do not contain useful fingerprint information. When minutiae extraction algorithms are applied to the background regions of fingerprint image, it results in the extraction of noisy and

false minutiae in image. Thus, segmentation is employed to remove background regions of image [17, 29].

In a fingerprint image, the background regions generally present a very low gray-scale variance value, where as the foreground regions of fingerprint image have a very high variance. Hence, a method is used which is based on variance threshold can be used to perform the segmentation. Firstly, the input image is divided into blocks and the grey-scale variance is calculated for each block in the fingerprint image. If the variance is less than global threshold, then the block is assigned to be a background region of image; otherwise, it is assigned to be part of the foreground of image. The grey-level variance for a block of size $W * W$ is defined as [29]:

$$V(k) = \frac{1}{W^2} \sum_{i=0}^{w-1} \sum_{j=0}^{w-1} (I(i,j) - M(k))^2,$$

(3)

Where $V(k)$ is the variance for block k, $I(i; j)$ is the grey-level value at pixel $(i ; j)$, and $M(k)$ is the mean grey-level value for the block k.

3.3. NORMALIZATION

The next step in the fingerprint enhancement process is image normalization. Normalization is done so that the gray level values lies within a given set of values. The fingerprint image is normalized using a predefined mean and variance values. This is required as the image usually has distorted levels of gray values among the ridges and the valleys as input. Normalization allows standardizing the distorted levels of variation in the gray scale values among ridges and valleys. Normalization performs pixel-wise operations and does not change the ridge and valley structures of image. Normalization is a linear process. Suppose the intensity range of the fingerprint image is 50 to 180 and the desired range is 0 to 255 each of pixel intensity to make the range 0 to 130.Each pixel intensity is multiplied by 255/130, making the range 0 to 255. Normalization is used to standardize the intensity values in an image by adjusting the range of grey-level values so that it lies within a desired range of values. Let $I(i, j)$ represent the grey-level image at pixel (i , j) and $N(i,j)$ represent the normalized grey-level value at pixel (i,j). The normalized image is defined as [10, 28]:

$$G(i,j) = \begin{cases} M_0 + \sqrt{\dfrac{VAR_0(I(I,J)-M)^2}{VAR}} & \text{if } I(i,j) > M \\ M_0 - \sqrt{\dfrac{VAR_0(I(I,J)-M)^2}{VAR}} & \text{otherwise} \end{cases}$$

(4)

Where M and V are the estimated mean and variance values of I (i, j), respectively, and M0 and V0 are respectively the desired mean and variance values of image [10].

Normalization does not change the ridge structures in a fingerprint; it is performed to standardize the dynamic levels of variation in gray-level values which facilitates the processing of subsequent image enhancement stages.

3.4 ORIENTATION ESTIMATION

The orientation field of a fingerprint image defines the local orientation of the ridges contained in the fingerprint (see Figure 2.) [20]. The orientation estimation is a fundamental step in the enhancement process as the subsequent Gabor filtering stage relies on the local orientation in order to effectively enhance the fingerprint image. The least mean square estimation method employed by Hong et al. is used to compute the orientation of input image.[23, 24, 29]. However, instead of estimating the orientation block-wise, I have chosen to spread their method into a pixel-wise scheme, which produces more accurate estimation of the orientation field.

The steps for calculating the orientation of image at pixel (i, j) are as follows:

1. Firstly, a block of size W x W is centered at pixel (i, j) in the normalized fingerprint image.
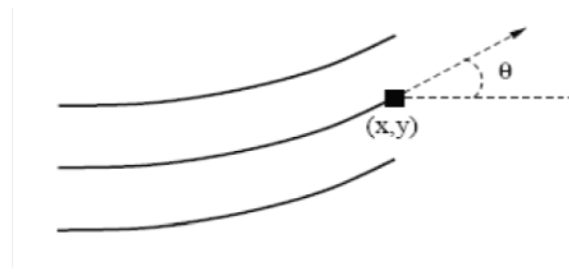

Figure 3: The orientation of a ridge pixel in a fingerprint [9].

2. For each pixel in the block, compute the gradients $\partial x(i, j)$ and $\partial y(i, j)$, which are the gradient magnitudes in the x and y directions, respectively. The horizontal Sobel operator is used to compute as $\partial x(i, j)$:

$$\begin{pmatrix} 1 & 0 & -1 \\ 4 & 0 & -4 \\ 1 & 0 & -1 \end{pmatrix}$$

(5)

The vertical Sobel operator is used to compute as $\partial y(i, j)$:

$$\begin{pmatrix} 1 & 4 & 1 \\ 0 & 0 & 0 \\ -1 & -4 & -1 \end{pmatrix}$$

(6)

3. The local orientation at pixel (i, j) can then be estimated using the following [1, 23, 28,29]:

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

(7)

$$\mathcal{V}_y(i,j) = \sum_{u=i-\frac{w}{2}}^{i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{j+\frac{w}{2}} \left(\partial_x^2(u,v)\partial_y^2(u,v) \right),$$

(8)

$$\theta(i,j) = \frac{1}{2} \tan^{-1} \left(\frac{\mathcal{V}_y(i,j)}{\mathcal{V}_x(i,j)} \right),$$

(9)

Where θ (i, j) is the least square estimate of the local orientation at the block centered at pixel (i,j) [23].

4. Smooth the orientation field in a local neighborhood using a Gaussian filter. The orientation image is firstly converted into a continuous vector field, which is defined as [23]:

$$\Phi_x(i, j) = \cos(2\theta(i, j)), \qquad (10)$$

$$\Phi_y(i, j) = \sin(2\theta(i, j)), \qquad (11)$$

Where φx and φy are the x and y components of the vector field, respectively. After the vector field has been computed, Gaussian smoothing is then performed as follows [29]:

$$\Phi'_x(i, j) = \sum_{u=-w_\Phi/2}^{w_\Phi/2} \sum_{v=-w_\Phi/2}^{w_\Phi/2} W(u, v)\Phi_x(i - uw, j - vw)$$

$$\qquad (12)$$

Where G is a Gaussian low-pass filter of size w *w.

5. The final smoothed orientation field O at pixel (i,j) is defined as [29]:

$$O(i, j) = \frac{1}{2} \tan^{-1}\left(\frac{\Phi'_y(i, j)}{\Phi'_x(i, j)} \right) \qquad (13)$$

3.5 RIDGE FREQUENCY ESTIMATION
In addition to the orientation image, another important parameter which is applied to construction of the Gabor filter is the local ridge frequency. The frequency image represents the local frequency of the ridges in a fingerprint. The first step in the frequency estimation stage is to divide the image into blocks of size W x W The next step is to project the grey-level values of all the pixels located inside each block along a direction orthogonal to the local ridge orientation [25-27].   This projection forms an almost sinusoidal-shape wave with the local minimum points corresponding to the ridges in the fingerprint.
I have modified the original frequency estimation stage used by Hong et al. to include an additional projection smoothing step prior to computing the ridge spacing. This involves smoothing the projected waveform using a Gaussian low pass filter of size w x w to reduce the effect of noise in the projection. The ridge spacing S(i,j) is then computed by counting the median number of pixels between consecutive minima points in the projected waveform. Hence, the ridge frequency F, for a block centered at pixel is defined as:

$$F (i,j) = 1/ S(i,j), \qquad (14)$$

Given that the fingerprint is scanned at a fixed resolution, then ideally the ridge frequency values should lie within a certain range. However, there are cases where a valid frequency value cannot be reliably obtained from the projection. Examples are when no consecutive peaks can be detected from the projection, and also when minutiae points appear in the block. For the blocks where minutiae points appear, the projected waveform does not produce a well-defined sinusoidal shape wave, which can lead to an inaccurate estimation of the ridge frequency. Thus, the out of range frequency values are interpolated using values from neighboring blocks that have a well-defined frequency [15, 25, 27, 28].

3.6 GABOR FILTERING
Once the ridge orientation and ridge frequency information has been determined, Gabor filter is applied to filter the quality of image. A two dimensional Gabor filters consist of a sinusoidal plane wave of a particular orientation and frequency, regulate by a Gaussian envelope. Gabor filters are used because they have frequency-selective and orientation-selective properties. These properties allow the filter to be tuned to give maximal response to ridges at a specific orientation and frequency in the fingerprint image. Therefore, a properly tuned Gabor filter can be used to effectively maintain the ridge structures while removing noise [2,29]. The even-symmetric Gabor filter is the real part of the Gabor function, which is given by a cosine wave modulated by a Gaussian (see Figure 3). An even symmetric Gabor filter in the spatial domain is defined as [10, 12, 28]:

$$h(x, y : \phi, f) = \exp\left\{ -\frac{1}{2}\left[\frac{x_\phi^2}{\delta_x^2} + \frac{y_\phi^2}{\delta_y^2} \right] \right\} \cos(2\pi f x_\phi),$$

$$\qquad (15)$$

$$X_\phi = x \cos\phi + y \sin\phi, \qquad (16)$$

$$y_\phi = -x \sin\phi + y \cos\phi, \qquad (17)$$

Where ϕ is the orientation of the Gabor filter, f is the frequency of the cosine wave, δx and δy are the standard deviations of the Gaussian envelope along the x and y axes, respectively, and x_ϕ and y_ϕ define the x and y axes of the filter coordinate frame, respectively [10, 12].
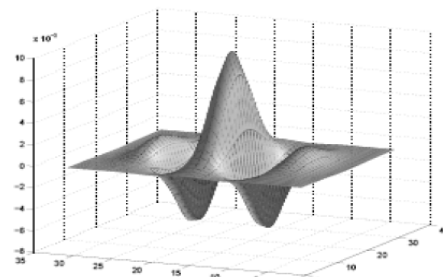

Figure 4: An even-symmetric Gabor filter in the spatial domain [9]

The Gabor filter is applied to the fingerprint image by spatially convolving the image with the filter.
 To apply Gabor filters to an image, three parameters must be specified:
1) The frequency of the sinusoidal plane wave, f,
2) The filter orientation, and
3) The standard deviations of the Gaussian envelope, dx and dy [9].

4. RESULTS

The main objective of a fingerprint enhancement is to improve and enhance the ridges and valleys structure of original fingerprint images. This process makes them more suitable for the minutiae extraction and recognition algorithm. The output parameter for evaluating such an enhancement algorithm is the percentage of quality improved. This improvement can be seen by analytical inspection. In this work, two output parameters have been used i.e correlation coefficient and Goodness Index. from Goodness Index value, by comparing input image and enhanced image. However, a precise and consistent characterization of the quality improvement is beyond the capability of subjective evaluation. Different stages of proposed algorithm are shown by screen shots of output at same stage. From these figures, it can be checked that proposed algorithm improves the clarity of the ridge and valley structures of input fingerprint images. The simulation work has been done using MATLAB R2008a as a platform using image processing toolbox and generalized MATLAB tool box. An image 118_1.tif has been taken for implementation purpose shown in fig4. After that, histogram of gray-scale input image is shown followed by that of histogram equalized image shown in fig.5. and fig 6. After that, normalized and renormalized image is calculated shown in fig.7. and fig.8 . After that, segmented and filtered image is shown in fig 9 and fig.10 followed by binary normalized image shown in fig.10.
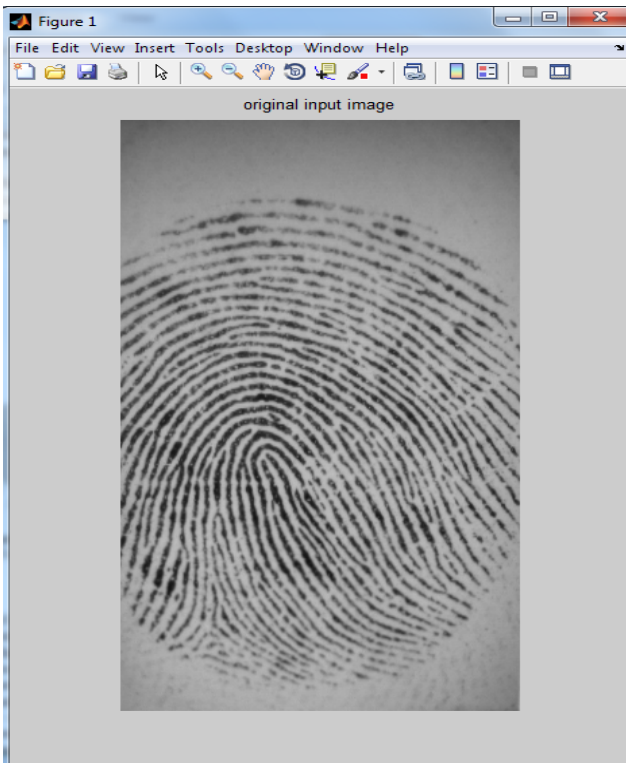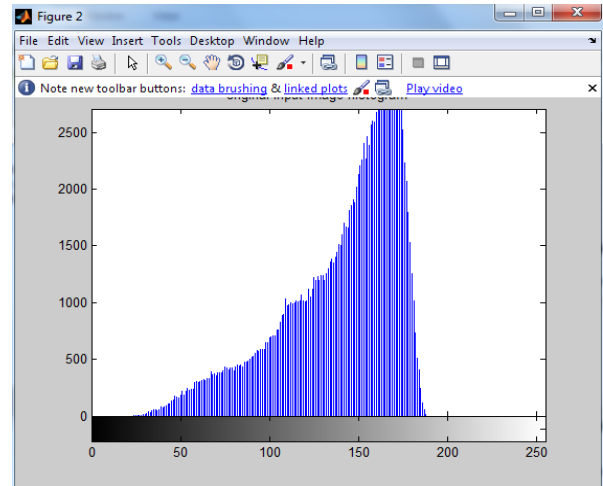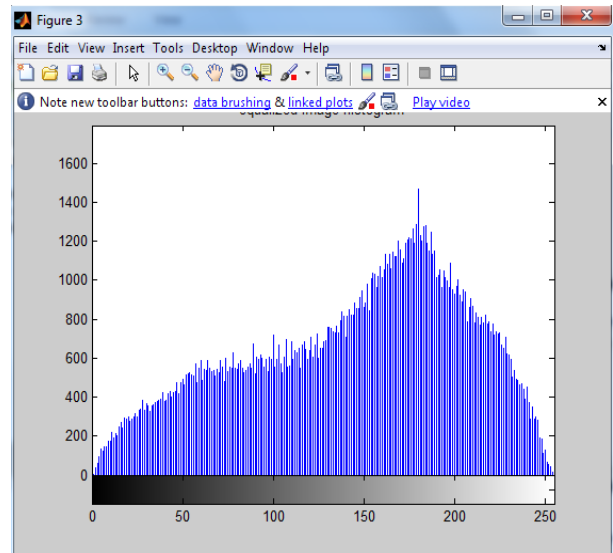

Fig.5 Histogram of input image

Fig.6. Histogram of adaptive equalized image

Fig.4 input finger print image

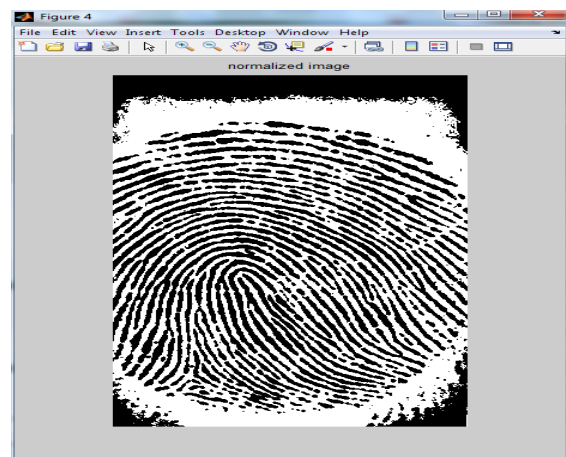
Fig.7 enhanced normalized ridge image
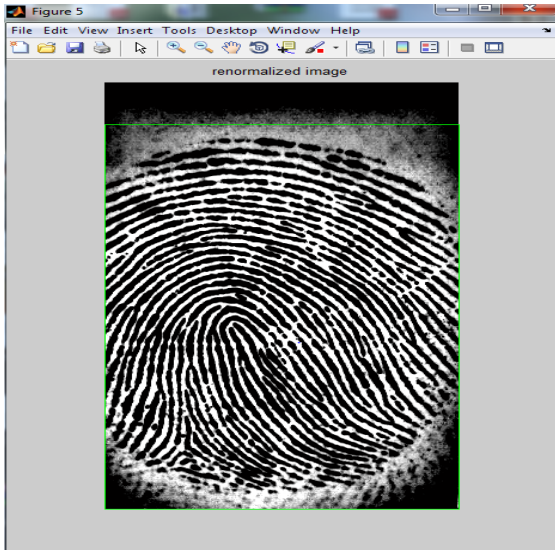
Fig.8. renormalized image with segment boundary

Fig.9. enhanced segmented image

Fig.10 Filtered image by Gfs and Wavelet Transform

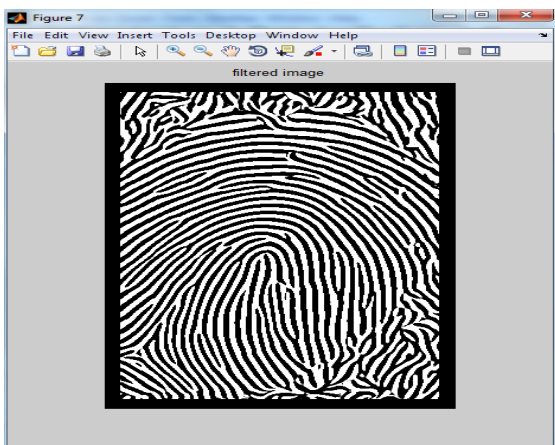Fig.11. filtered bi-normalized image

Also, a table is given which presents both output parameters for 10 different fingerprint images.

Image name	Correlation coefficient	Goodness Index
118_1.tif	0.7990	0.9358
118_2.tif	0.7775	0.9227
118_3.tif	0.7276	0.8853
111_1.tif	0.7387	0.9600
111_2.tif	0.8294	0.9428
111_3.tif	0.8208	0.9016
112_1.tif	0.8160	0.9178
112_2.tif	0.7348	0.9264
112_3.tif	0.7463	0.9620
114_1.tif	0.8263	0.9968

Table1. Goodness Index and Correlation coefficient of proposed method.

CONCLUSION AND FUTURE WORK

In this work, we have developed a fast fingerprint enhancement algorithm or technique which can adaptively improve the clarity of ridge and valley structures based on the local ridge orientation and ridge frequency estimated from the input image. The performance of the algorithm was evaluated using the goodness index of the extracted minutiae and the performance of an online fingerprint verification system which incorporates our fingerprint enhancement algorithm in its minutiae extraction module. Experimental results show that our enhancement algorithm is capable of improving both the goodness index and the verification performance.

Our algorithm also identifies the unrecoverable corrupted regions in the fingerprint and removes them from further processing. This work has described a method for RF estimation using curved regions and image enhancement by filters. In comparison with existing enhancement methods, For low-quality fingerprint images, improvements of the performance have been shown. The experimental results show that the proposed scheme is able to handle various input contexts and achieves the best performance in combination with existing verification algorithms. It is

noted that the operation has been performed on MATLAB platform in our simulation.

The future works related to this paper are as follows. Pixel processing could be used instead of block processing to reduce the computation complexity, and try to improve the speed of the proposed method. Moreover, the proposed method with fixed feature is very suited for a secure biometric system coupling it with bio-hashing, which can be used in cancelable biometrics by canceling and reissuing biometric templates and for protecting privacy in biometrics systems. Other improvement is that the potential of the matching performance rests upon a better OF estimation.

As long as OF estimation errors occur, it is necessary to choose the size of the GFs and the standard deviations of the Gaussian envelope with care in order to balance strong image smoothing while avoiding spurious features. An exploration of a locally adaptive choice of these parameters, depending on the local image quality and for example the local reliability of the OF estimation. In addition, it will be of interest to apply the curved-region-based RF estimation and curved GFs to latent fingerprints.

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