Study of the Effect of Pre-Processing on Spectral Minutiae Representation for Fingerprint Verification

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***Abstract*— The advent of biometrics based technology has automated the traditional method of identifying a person. Among all biometric identifiers, fingerprint based recognition has received much attention because of its high degree of distinctiveness and permanence, with the advantage of low cost and ease to access. There are three fingerprint matching approaches namely image-based, ridge feature based and minutiae based verification. Most of fingerprint recognition systems are based on minutiae matching. In minutiae based matching technique, pre-processing of fingerprint image is a necessary step. Two different pre-processing methods are introduced in this work. Pre-processing is followed by extraction of minutiae. The spectral minutiae representation is proposed in this work. This method is inspired by the Fourier-Mellin Transform in which the representation of input image is translation, rotation and scaling invariant. Two types of spectral representations: position based and orientations based are coded from the minutiae's information. The present work is the study of the effects of pre-processing techniques on these spectral representations, used for fingerprint verification. Two databases: A and B of 500 and 50 fingerprints from 100 and 10 fingers respectively, with five sample of each finger were used. Fingerprints images were collected from two public domain databases FVC (Fingerprint Verification Competition) 2002 and FVC 2004.**

Keywords*— *Biometric Systems, Fingerprint verification, Minutiae, Pre-processing

I. INTRODUCTION

Biometric system is providing the possibility to confirm one's identity by determining "who they are" rather than "what they possess or remember". Biometric systems are automated methods of recognizing the identity of a person on the basis of physiological or behavioural characteristics [1]. Among the several biometric identifiers, fingerprint has become a successful and widely used biometric today. In automatic identity management systems, Fingerprint is gaining attention exponentially because of its accuracy at low cost and ease of access comparatively to others.

Fingerprint contains much information that can be used for verification or identification purpose. Among them some of the features are ridges patterns, their counts at particular area of interest and minutiae etc. Minutiae are the ridges termination and bifurcation points. Nowadays many fingerprint based verification system uses minutiae information [2], [3]. In Minutiae based matching techniques pre-processing of fingerprint sample is a requisite step. Pre-processing comprises of binarization, thinning and noise removal. Two different thinning methods: Block filtering and Central line are introduced in this work. Each of this thinning approach with binarization and noise removal frames two different pre-processing concepts. In minutiae based fingerprint verification system it can be observe that, the minutiae location and orientation in minutiae set are unordered. It suffers from many distortions such as translation, rotation and scaling. This work is an attempt to overcome the same and to present the minutiae set as a fixed-length feature vector. This feature vector is spectral minutiae representation [9]. The present work is the study of the effects of pre-processing techniques on these spectral representations, used for fingerprint verification.

This paper is organised as follows: first in section II there is the characteristics of used databases. Next in section III, the detailed algorithm steps are presented. At last section IV and V contains experimental results, discussion and finally conclusions.

II. DATABASE

The fingerprints sample used for present work was selected from the database used in FVC (Fingerprint Verification Competition) 2002 and FVC 2004.

Two databases are designed: X and Y. Database X and Y contains fingerprint samples from FVC 2002 DB3 (set B) [4] and FVC 2004 DB3 (set A) [5] respectively. Among eight impressions of each fingerprint, only five impressions were selected. Since the algorithm is dependent on image quality only comparatively better quality images are selected for performance evaluation of the present work. The quality measurement that is used here is variance of image sample [6]. There are 10 and 100 fingerprints in organised X and Y database respectively, and five impressions of each sample.

In some of the fingerprints group (a fingerprint with all of its impression), couple of the sample was intentionally rotated to analyse the performance effectively.

III. ALGORITHM

The flowchart of proposed algorithm is as shown in Fig.1.

A. Minutiae Extraction

Pre- processing of original fingerprint image is a requisite step, in order to get consistent results. These steps include binarization and thinning of the input image. Following the thinning process, a final stage of noise removal is conducted to eliminate noise produced from the binarization and thinning processes.

Thinning refers to the reduction of all ridges lines to a single pixel width. There are varieties of thinning methods; we have involved two of them. The first technique involves thinning along the outer boundary of the ridges via a block filter. The second technique is an advanced method originally proposed by Ahmed and Ward [7] that focuses on thinning the ridges to their central lines.

Block Filtering attempts to preserve the outermost pixels along each ridge. It begins with reduction of ridge width to enable more effective block filtering. Then from right to left and left to right there is passage of block filter to preserve the outer boundaries of ridge.

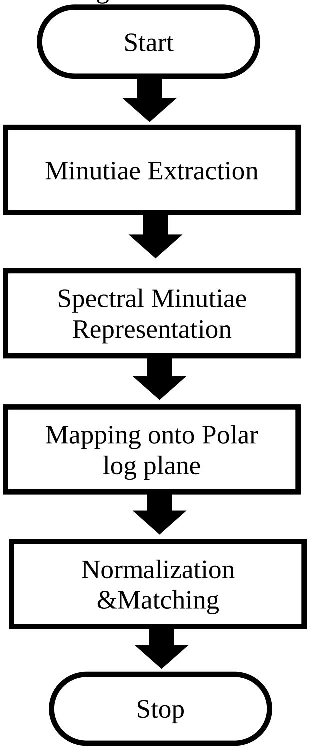

Fig.1: Flowchart of proposed Fingerprint based verification

Immediately after this the unwanted segments produced in previous step are removed. Following this images from left to right and right to left filtering are combined into one image. Then there is further thinning by elimination of one pixel from two by two square of black. Short line segments proturbing from ridges after scan combination are removed. Atlast some imperfection such as duplicate horizontal and vertical lines are removed.

Central line thinning involves reducing the individual ridges to a width of one pixel at their central lines. The rule-based algorithm developed for character recognition by Ahmed and Ward [7] can be applied to a fingerprint image. This method is an iterative approach. In each iteration, the algorithm deletes those points that lie on the outer boundaries of the ridges, so long as the width of the ridge is greater than one pixel. Twenty one rules were used; the first twenty rules were originally proposed by Ahmed and Ward [7], while the twenty-first rule was introduced by Patil, Suralkar, and Sheikh [8] for specific application to fingerprint images. Once the iteration is complete, *Patil, Suralkar, and Sheikh* [8] discovered that the process does not completely thin diagonal lines to a width of one pixel. As a result, they proposed applying an additional set of rules to follow the thinning process proposed by Ahmed and Ward [7], designed specifically for diagonal lines. As described in [1], one possible approach for this process involves computing the crossing number. Crossing number is defined as half the sum of differences between pairs of adjacent pixels that surround the given black pixel. At the outer boundaries of the image the ridges come to an end, which are classified as termination. But actually these are false minutiae, which should not be recorded as minutiae within the fingerprint. One possible solution to eliminate such locations involves creating an ellipse to only select minutiae points inside the fingerprint image.

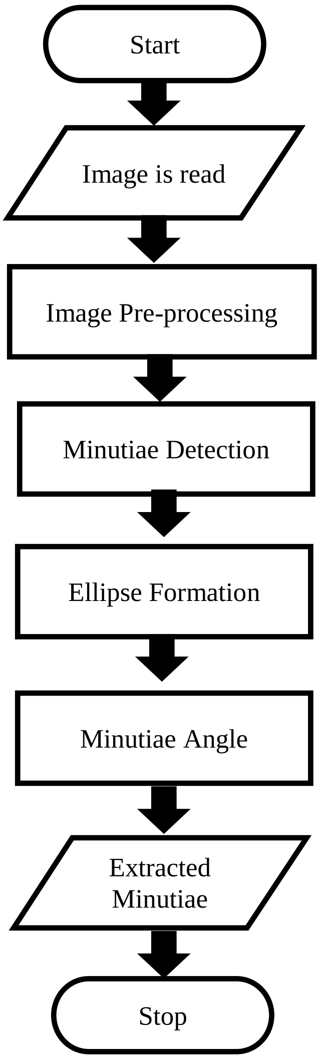

Fig.2: Flowchart of minutiae extraction

In order to compute the minutiae angle, here we need to define termination and bifurcation angle. An Angle between

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the horizontal and the direction of the ridge is called termination angle. Horizontal line and the direction of the valley ending between the bifurcations together make an angle called bifurcation angle. The concept of termination and bifurcation duality [1] says that a termination in a black and white image corresponds to a bifurcation in its negative image and vice versa. As a result, the original black and white image is inverted to obtain the bifurcation angles. The negative image is then thinned using any one of the methods described previously. The detailed steps in minutiae extraction can be understand by the flowchart shown in Fig. 2.

B. Spectral Minutiae Representation

Discrete Fourier transform of an image, yields a representation of a periodic repetition of the original image. Secondly, when it is remapped onto a polar–logarithmic plot, interpolation artifacts are introduced. Thus in order to overcome these defects, each minutia in the spatial domain is represented as a Dirac pulse. Based on the information of minutiae two types of spectral representations are introduced [9]:

- Spatial Minutiae Spectrum (SMS).
- Directional Minutiae Spectrum (DMS).

C. Spatial Minutiae Spectrum (SMS)

This spectral representation codes the location information of minutiae. So very clearly SMS for N numbers of minutiae is defined as

$$F_{SMS}(w_x, w_y) = \sum_{k=1}^{N} e^{(-j(w_x x_k + w_y y_k))} \qquad (1)$$

Now Gaussian low pass filter is used in order to reduce the sensitivity to small variation in spatial domain. This filter is used to attenuate the higher frequencies. Thus, in the spatial domain, each minutia is represented by an isotropic two-dimensional Gaussian function. A 2-D Gaussian in the space domain and its Fourier transform are respectively as follows

$$g(x, y) = \frac{1}{2\pi\sigma^2} e^{\left(-\frac{x^2+y^2}{2\sigma^2}\right)} \xleftrightarrow{F} G(w_x, w_y) = e^{\left(-\frac{w_x^2+w_y^2}{2\sigma^{-2}}\right)} \qquad (2)$$

Implementing the shift property of the Fourier Transform the magnitude of F_{SMS} is only retained to make the spectrum translation invariant, and thus we have

$$\left|F_{SMS}(w_x, w_y; \sigma_L^2)\right| = \left|F_{SMS}(w_x, w_y) e^{\left(-\frac{w_x^2+w_y^2}{2\sigma^{-2}}\right)}\right| \qquad (3)$$

The expression (3) is evaluated on a polar-logarithmic grid. The resulting expression in this domain is translation invariant, and rotation, scaling of the input has become translation along the coordinates of polar-log plot. Fig. 3 shows a SMS of a fingerprint.

D. Directional Minutiae Spectrum (DMS)

The SMS only uses the information regarding the location of minutiae. However, including the orientation of minutiae as well, may give better discrimination. So, it can be advantageous to also include the orientation information in our spectral representation. DMS codes both location and orientation of minutiae. As presented earlier the orientation of a minutia is available at third column of minutia text file.

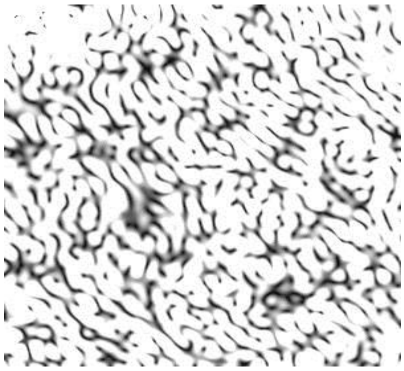

Fig. 3. Spatial Minutiae Spectrum (SMS) of a Fingerprint Image

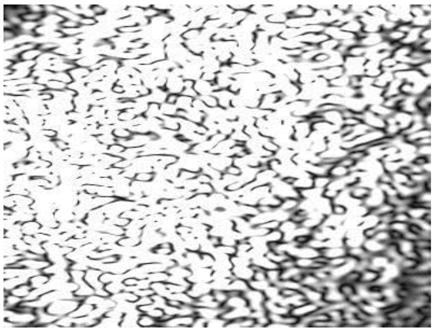

Fig. 4. DMS of a Fingerprint

$$\left|F_{DMS}(w_x, w_y; \sigma_o^2)\right| = \left| e^{\left(-\frac{w_x^2+w_y^2}{2\sigma^{-2}}\right)} \sum_{k=1}^{N} j(w_x \cos\alpha_k + w_y \sin\alpha_k) e^{-j(w_x x_k + w_y y_k)} \right| \qquad (4)$$

Thus, to every minutia in a fingerprint, a function $m_k(x, y, \alpha)$ is assigned. Likewise in SMS algorithm, using a Gaussian filter and only retaining the magnitude of the spectrum yields expression (4). Fig. 4 shows a DMS of certain fingerprint.

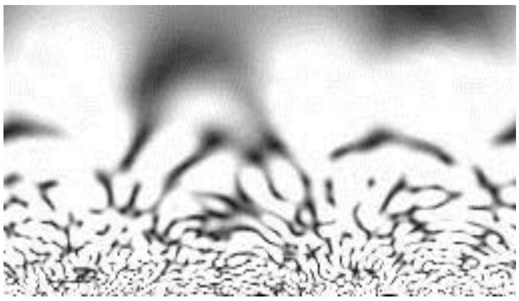

Fig. 5. An Example of Spectrum Sampled on Polar-Log Plane

E. Mapping onto Polar-Log Coordinates

Before this we have develop analytical expression for the spectral representation of minutiae. Moving towards our final spectral representation, the continuous spectral are remapped on a polar-logarithmic coordinate system. Fig. 5shows the final spectrum.

where, polar-logarithmic coordinates

$$\lambda = \log \sqrt{w_x^2 + w_y^2} \text{ and } \beta = angle(w_x, w_y) \qquad (5)$$

F. Matching

The two spectra (matching input) are normalised in order to have zero mean and unit energy. The process of comparison of two minutiae spectra is the final step in this recognition process. The outcome of matching is either match or no match, or we can say the result is totally absolute value. This is achieved by computing a value called matching score, which refers to the degree of similarity between two spectra. This score decides match and no match condition by the use of a threshold value [10].

In this algorithm the correlation of two spectral images was decided as matching score. Let S (m, n) and T (m, n) be the two spectral representations, respectively obtain from stored fingerprint and test fingerprint. We calculated the 2-D correlation coefficient between S and T and used it as a measure of their similarity.

The minutiae spectra we have obtained is translation invariant but not rotation and scaling invariant. The input fingerprint images can be rotated and scaled (depending on the sensor that is used to acquire an image). As we know rotation and scaling are translation in the spectral representation, so a procedure is developed to test some different combination of rotation and scaling. To be more precise rotation becomes circular shift in the horizontal direction and scaling becomes shift in the vertical direction [9].

Let T (m-i, n-j) be the translated version of T (m, n), with a shift of i and a circular shift of j in the vertical and horizontal direction respectively. Thus the correlation coefficient between S and T is defined as

$$R(i,j) = \frac{\sum_m \sum_n \{S(m,n) - \bar{S}\}\{T(m-i,n-j) - \bar{T}\}}{\sqrt{\left[\sum_m \sum_n \{S(m,n) - \bar{S}\}^2\right]\left[\sum_m \sum_n \{T(m-i,n-j) - \bar{T}\}^2\right]}} \qquad (6)$$

Where, $\bar{S} = \frac{\sum_m \sum_n S(m,n)}{m \times n}$ $\bar{T} = \frac{\sum_m \sum_n T(m,n)}{m \times n}$

There is no scaling difference between the fingerprints of most of the databases, or the same can be compensated for on the level of the minutiae sets [11]. Hence, now only few rotations need to be tested. The maximum score *M* among the different combination is the final matching score

$$M = \max_j \{R(0, j)\} \qquad (7)$$

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The response of a matcher in a fingerprint recognition system is typically a matching score (ranging in the interval [0, 1]) that quantifies the similarity between the input and the database template representations. The system decision is regulated by a threshold *th* pairs of fingerprints generating scores higher than or equal to *th* are inferred as matching pairs (i.e. belonging to the same finger); pairs of fingerprints generating scores lower than *th* are referred as non-matching pairs (i.e. belonging to different fingers). In this work, two databases have been used. The result associated to each database is discussed here after.

A. Result on Database X

Database X is a small database of 10 fingerprints and 5 sample of each. Each sample is pre-processed and passed through the steps proposed in algorithm to obtain the final normalised spectral minutiae representation. Then 2D correlation coefficient of stored and test sample is calculated, which is considered as matching score for this present work.

Two pre-processing techniques (Block Filtering and Central Line) were used and their corresponding spectral representation was used for verification purpose. The performance of verification was carried out in order to analyse the effect of pre-processing techniques.

The performance is evaluated by calculating the FMR and FNMR for different threshold. Then Decision Error Trade-off (DET) is plotted to determine the equal error rate (EER). Finally EER value can be considered for analysing the performance, lower the EER, higher the accuracy of the system. Formal definition of FMR, FNMR and EER are given in [12]. In the designed performance Table 1, the first column is containing two different thinning methods. As the remaining binarization and noise removal step are common in both pre-processing approach, thus only thinning method has the effect on two different spectral representations, mentioned in second column. In order to check the proposed algorithm more accurately, two experiments has been conducted. Experiments include analysis using original database and database excluding the rotated sample. A beautiful combination of these conditions can bepresented as in Table 1. The corresponding DET plot is also mentioned in brackets in last column along with EER value.

Table-1: Matching Performance Table for Database X

Pre-processing Method	Spectral Representation	Experiments	EER (Fig. number)
Block Filtering	SMS	All	21.9 (Fig. 6a)
		Excluding rotated images	10.21 (Fig. 6b)
	DMS	All	18.16 (Fig. 6c)
		Excluding rotated images	9.8 (Fig. 6d)
Central Line	SMS	All	7.6 (Fig. 6e)
		Excluding rotated images	1.2 (Fig. 6f)
	DMS	All	6.84 (Fig. 6g)
		Excluding rotated images	1.77 (Fig. 6h)

B. Result on Database Y

This section contains the result on second database Y. This database consists of fingerprints from 100 subjects and 5 samples of each. A Similar performance table as for FVC 2002 is also presented for FVC 2004 as Table 2.

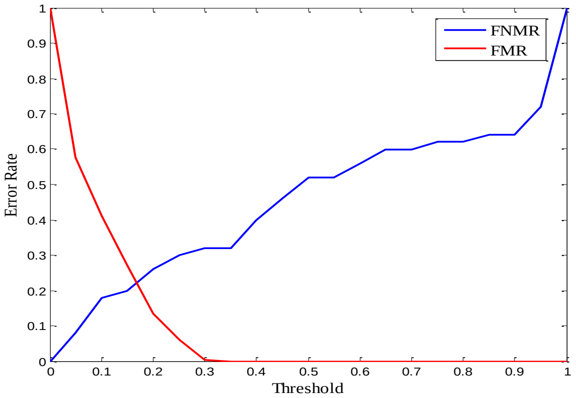

Fig.6a

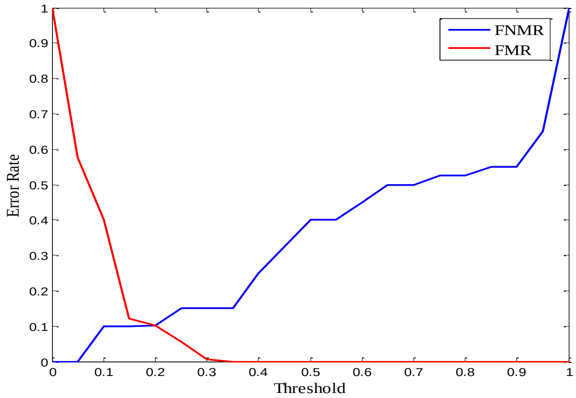

Fig.6b

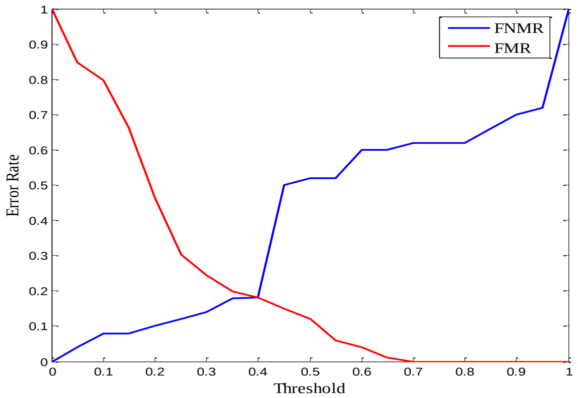

Fig.6c

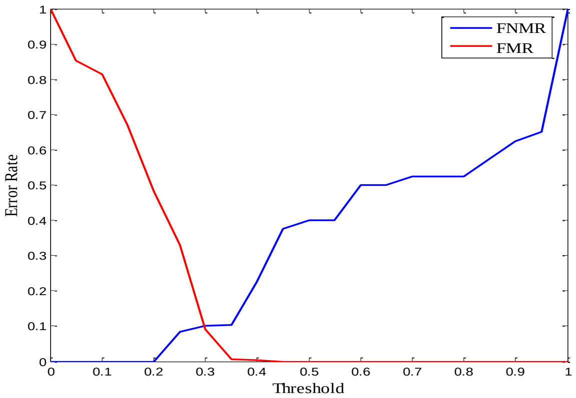

Fig.6d

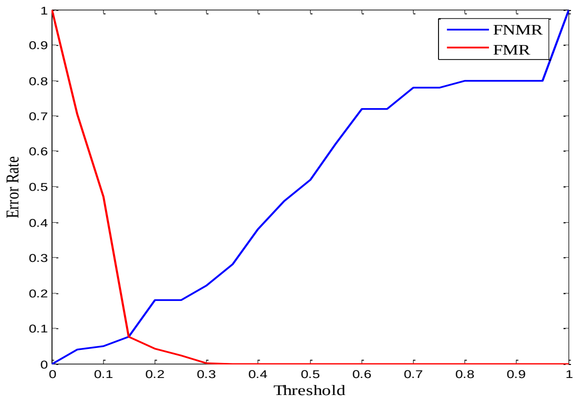

Fig.6e

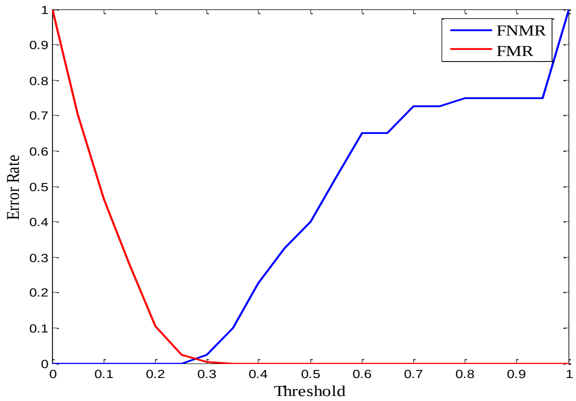

Fig.6f

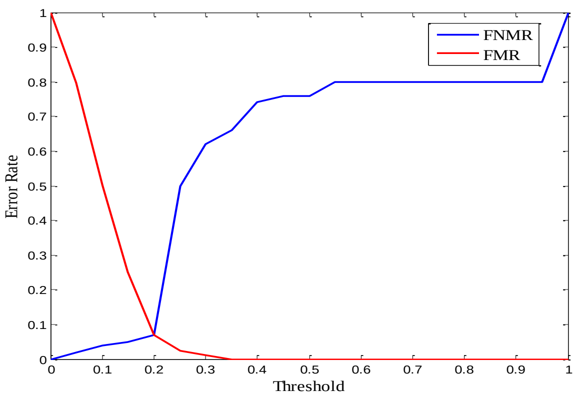

Fig.6g

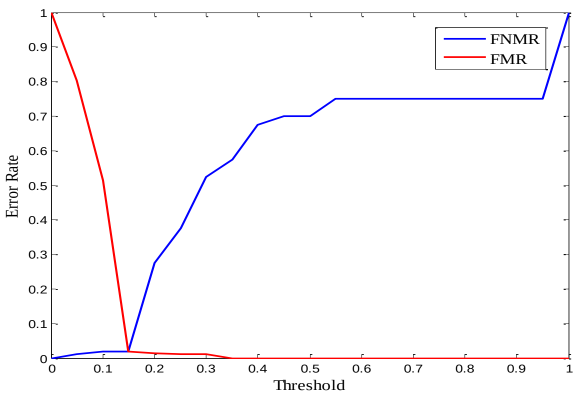

Fig.6h

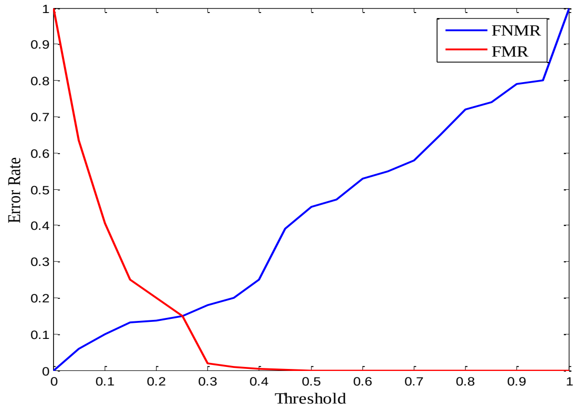

Fig.7a

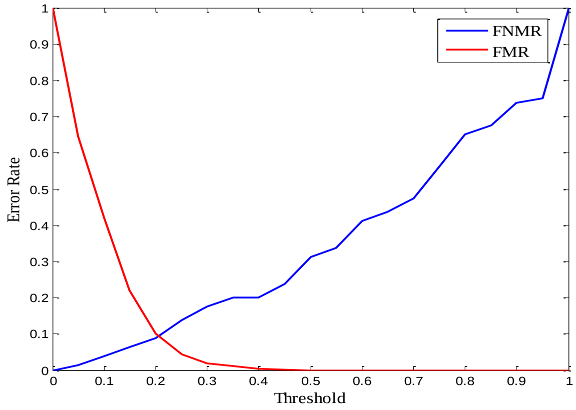

Fig.7b

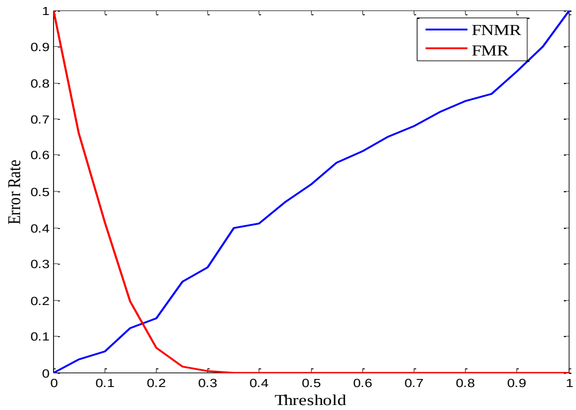

Fig.7c

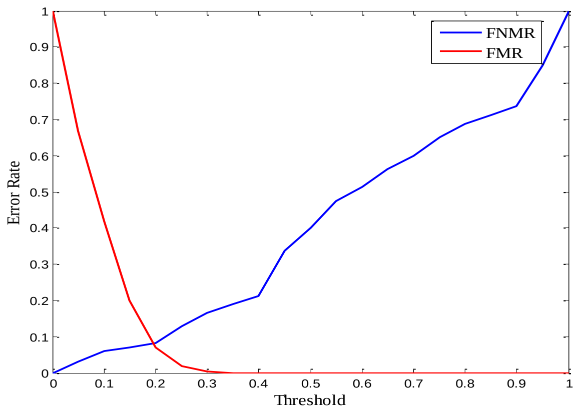

Fig.7d

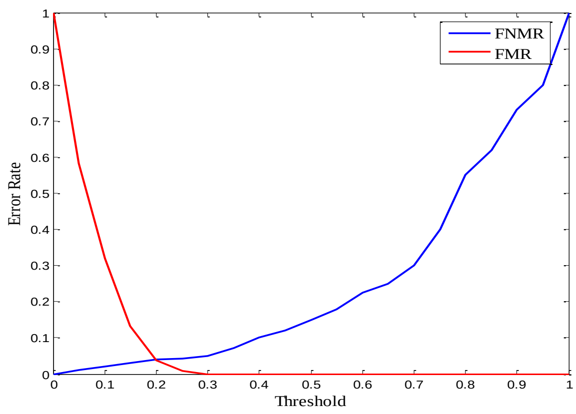

Fig.7e

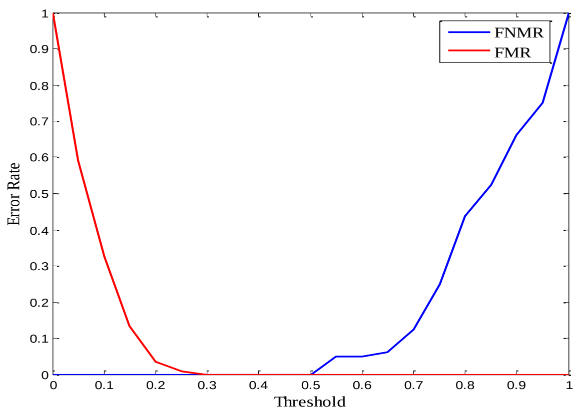

Fig.7f

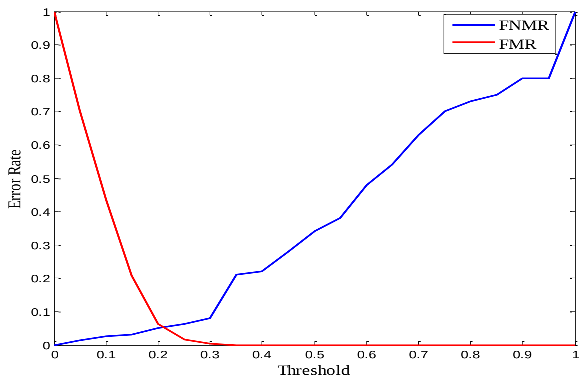

Fig.7g

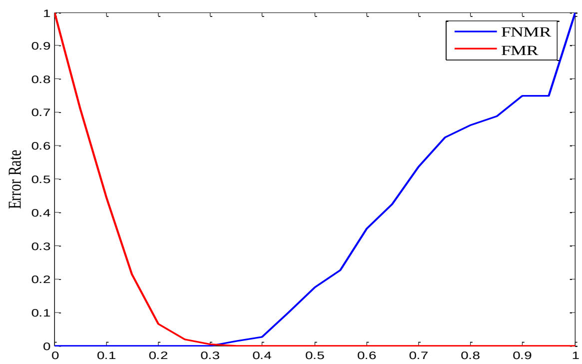

Fig.7h

Following chief points can be made from the results presented before:

- Algorithm is very much sensitive to image quality, as all the EER value of Database Y is found comparatively less than corresponding values of Database X.
- Result shows that using the central line thinning method for pre-processing, provides good recognition rates. The central line thinning main strength lies in its ability to thin ridges and maintain its integrity.
- It can also be seen that DMS spectral results is always having comparatively lower EER than SMS. Only in table 2, EER for DMS is slightly more than SMS but the difference is acceptable.
- In rotated images some minutiae (very less) are lost at the boundaries, so two experiments were carried out, which help us to conclude on same. Difference between EER of two experiments is less for central line than block filtering thinning method. The Central line thinning is maintaining the ridge structure regardless of rotation, making it easier to effectively process all types of input images.

Table-2: Matching Performance Table for Database Y

Pre-processing Method	Spectral Representation	Experiments	EER: Equal Error Rate (Fig. Number)
Block Filtering	SMS	All	15 (Fig. 7a)
		Excluding rotated images	9.2 (Fig.7b)
	DMS	All	13.26 (Fig. 7c)
		Excluding rotated images	7.93 (Fig. 7d)
Central Line	SMS	All	3.37 (Fig. 7e)
		Excluding rotated images	0 (Fig. 7f)
	DMS	All	5.23 (Fig. 7g)
		Excluding rotated images	0 (Fig. 7h)

V. CONCLUSION

Various steps are required for a reliable fingerprint recognition system. The first step involves pre-processing the original fingerprint image. This includes image binarization, ridge thinning, and noise removal. After this pre-processing phase is complete, the minutiae extraction step is executed. These minutiae sets are suffered from several deformations such as translation, rotation and scaling. The proposed Fourier Mellin based spectral minutiae representation overcomes this limitation. This method is compatible to large number of minutiae databases. Both spectral representation (location based and orientation based) depends on good quality of fingerprint and/or the reliability of minutiae extraction. Minutiae extraction is further dependent on pre-processing of input. The work presented in this thesis is the study of performance of fingerprint verification system for two different pre-processing techniques applied on two types spectral representations. A beautiful combination of pre-processing and spectral representation was carried out and the performance of verification was studied.

Further, a much advanced area of future work could involve incorporating this study with another biometric in developing a multimodal system.

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