The Nucleus

Partial Fingerprint Image Enhancement using Region Division Technique and Morphological Transform

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A B S T R A C T

Fingerprints are the most renowned biometric trait for identification and verification. The quality of fingerprint image plays a vital role in feature extraction and matching. Existing algorithms work well for good quality fingerprint images and fail for partial fingerprint images as they are obtained from excessively dry fingers or affected by disease resulting in broken ridges. We propose an algorithm to enhance partial fingerprint images using morphological operations with region division technique. The proposed method divides low quality image into six regions from top to bottom. Morphological operations choose an appropriate Structuring Element (SE) that joins broken ridges and thus enhance the image for further processing. The proposed method uses SE "line" with suitable angle θ and radius r in each region based on the orientation of the ridges. The algorithm is applied to 14 low quality fingerprint images from FVC-2002 database. Experimental results show that percentage accuracy has been improved using the proposed algorithm. The manual markup has been reduced and accuracy of 76.16% with Equal Error Rate (EER) of 3.16% is achieved.

1. Introduction

Biometric deals with identification/verification of an individual by using certain physiological or behavioral traits that are associated with a person. Fingerprint is the most reliable technique because of its small size, lower cost of devices, ease of integration, high accuracy and above all they do not change throughout the life of a person except due to accident, cuts or wrinkles on fingertips [1]. Fingertip of every human being is a series of small grooves and valleys that are arranged in a pattern along the surface of the finger. These grooves are also known as ridges and the patterns that are formed by these ridges are unique to every human being [2]. Many techniques and algorithms have been proposed for good quality fingerprints that are visible and precisely taken by ink pad or live scan. These algorithms yield very accurate results. However, the algorithms proposed for good quality fingerprints does not give precise and accurate results when input is a low quality (partial) or poor quality (latent) fingerprint images. Low quality fingerprint images are acquired due to variations in impression conditions. Although fingerprint impression is taken through scanner, still they sometime fails to produce accurate impression because of pressure intensity, dryness, weak signal, disease or secretion on fingertips. This results in partial fingerprint images. Moreover, the fingerprint contains residue such as ink, dirt, powder, grease, blood or other body fluids [2]. These types of fingerprints are often made by accident or chance and are

known as latent fingerprints. The various types of fingerprint images are shown in Fig. 1. Latent fingerprints are mostly invisible by naked eye [2]. They may lie on difficult surfaces such as porous fabrics or rough materials like wood, paper, aluminum foil, glass etc. Often only a small fraction of the finger makes contact with the surface resulting in a partial fingerprint and the fingerprint may be smudged or have degraded over time. Therefore they come across as limitations while extraction and enhancement.

Fig. 1: Three different qualities of fingerprint image. (a) Good quality fingerprint (b) Partial fingerprint (c) Latent fingerprint

Fingerprint identification/verification has a wide range of acceptance in commercial and law enforcement applications. It is one of the most important evidence in crime scenes investigation. More crimes have been solved with fingerprint as an evidence than for any other reason [1]. Also it plays an important role in vote casting. An accurate and vivid thumb impression helps to identify an

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individual who has contributed in vote casting. Moreover, thumb impression verification for stamp papers are also one of the finest application of fingerprint images where accuracy is required.

Many algorithms proposed for good quality images have accurate results for feature extraction and matching. The low quality images are still a challenging problem. Therefore, low quality images are treated manually for identification which produces various errors when further treated for minutiae extraction and matching. In available reported work for low quality fingerprint images [1, 5, 7], researchers had applied their utmost efforts to develop new techniques in fingerprint enhancement through segmentation, normalization, orientation estimation, filtering, binarization, thinning etc. These techniques having different approaches to evaluate their performance and maintain the sequence accordingly. In order to further improve the performance of algorithms for low quality fingerprint images, an enhancement algorithm is needed to improve the image quality for genuine minutiae extraction. So far the enhancement is usually done on overall fingerprint image and an image in its pre-processing stage is usually undergone edge and contrast enhancement which is still not up to the mark as the broken ridge/valley pattern in low quality (partial) fingerprint images is to be touched in detail. The major key concern of the fingerprint image enhancement is to improve the ridge and valley structure for feature extraction [3].

2. Related Work

Saini [1] improved the quality of image by the histogram modeling which helped in gaining higher contrast. Various filtering methods are used to remove excessive noise, extract the edges of an image, restore the image and finally binarization and thinning is applied. Gill et al. [2] enhanced the fingerprint images using the effect of Principle Component Analysis (PCA) in which spectral analysis was conducted. This method has certain limitations as it is hard to extract spectral information from fingerprint because of natural secretions which are mostly transparent. Ashok et al. [3] enhanced the image by removing noise from input image using morphological operations for image enhancement, noise removal, image skeletonization and edge detection. Morphological operations (dilation & erosion) are used to remove noise from the input image with SE of size 3x3 window. Kale et al. [4] enhanced the low quality fingerprint image by using morphological approach. The input is a grey scale image which was first undergone to contrast enhancement by using spatial domain analysis. Noise was removed with the help of Gaussian linear spatial filtering and finally morphological tophat transform was applied to enhance the fingerprint image with SE disk shaped of radius 5. Ryu et al. [5] proposed an approach to enhance feature extraction for low-quality fingerprint images by

using stochastic resonance where an appropriate amount of noise prior Gaussian Noise was added to the original signal which increased the signal-to-noise ratio. Gabor filters were used for enhancement which did not recover the fingerprint patterns since local ridge direction or distance of the ridge flow were not visible in low-quality images. Karimi-Ashtiani [6] proposed robust technique which was based on orientations and frequencies estimation of fingerprints in a local region to allow Gabor filtering for fingerprint ridge/valley pattern enhancement. This robust technique does not work well on singular points and low resolution images. Yoont et al. [7] proposed an automated latent fingerprint enhancement algorithm which requires manual markup of Region of Interest (ROI) and singular points. The manual markup to calculate ROI produced worse results on poor and ugly quality latent's Deepika et al. [8] used Wavelet based normalization method for marking the ROI on fingerprint images so as to normalize illuminations for enhancement. Z. Yong et al. [9] proposed a fingerprint image enhancement algorithm using signature technique. First, signature is extracted from RGB by using human-computer interaction and Principal Component Analysis (PCA) method. The signature area was pointed with partial differential equation based method. Finally the ridges or valleys are enhanced according to image characteristics. Das et al. [10] enhanced the low quality fingerprint images by using morphological closing operation performed on the binary image to close the holes within ridges. The SE 'square' of size 2 x 2 was used. Patil et al. [11] enhanced the low quality fingerprint images by determining the block direction for each fingerprint image with window WxW in size (by default W is 16 pixels). Open and close morphological operations were used to expand image in order to remove noise caused by background and to shrink image to eliminating small cavities. Li et al. [12] enhanced the fingerprint image with free alignment crypto system by utilizing the rotation and translation-invariant features representation extracted from modified VNS (Voronoi Neighbor System). It was addressed by 3D quantization technique and based on fixed length bit string representation. Romdhane et al. [13] enhanced the fingerprint images based on the diffusion tensor approach which provides a robust anisotropic diffusion. It degraded the synthetic image with curves oriented with a high Gaussian noise in order to achieve signal-to-noise ratio. Raffaele et al. [14] used contextual based Gabor filtering for fingerprint image enhancement. The input image was taken by manual markup which is still challenging to make it automated. More than half false minutiae and 28% less missed minutiae are achieved while enhancing the fingerprint image using contextual based Gabor filtering technique. Malathai et al. [19] introduced novel method for partial fingerprint matching based on non-minutiae features such as pore and scale invariant feature transform

(SIFT) by using fusion technique. The algorithm was restricted to image size of 60% resolution.

From the above literature review, it has been deduced that previously good quality fingerprint images are producing best results for minutiae extraction and matching. Feature extractors reject an input image if the quality of fingerprint is low or partial [5]. However, low and poor quality fingerprint image preprocessing is critical in many identification/verification systems. It should be enhanced by different techniques but some or the other way they offer some limitations in feature extraction and matching. This is due to poor results of the pre-processing. The problem can be reduced if image enhancement component is taken into account which will help the feature extractor to find reliable features from low input fingerprint images. This aims to improve the quality of partial fingerprints.

3. Proposed Work

We proposed an algorithm to enhance the low quality fingerprint images in order to improve the ridge and valley structure for genuine feature extraction and matching. It uses morphological closing transform with region division on binary images with structuring element "line" having suitable radius r and angle θ in a specific region. The region division is not based on manual markup and each image taken as an input is divided into six regions without being restricted to image size. Therefore, any low quality fingerprint image can be enhanced by this channelized technique irrespective of its dimensions and resolution. The block diagram of proposed algorithm is shown in Fig. 2.
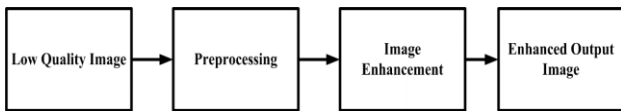
Fig. 2: Block diagram of proposed algorithm for low quality fingerprint image enhancement

Rest of the paper is organized as follows. Section 4 addresses the image pre-processing. Section 5 devoted to the proposed approach for image enhancement using morphological operation with region division. Experimental results that illustrate the performance of the proposed method are summarized in section 6. Section 7 concludes the work.

4. Image Pre-processing

In this section, the basic mathematical concepts for image preprocessing proposed in literature are presented and its application for noise removal and image enhancement for a low quality images. Strong preprocessing steps are required in order to enhance the low and poor fingerprint images. Preprocessing involves the following steps.

4.1. Histogram Modeling

Histogram of an image is the relative frequency of the various gray levels of an image having values from 0 to 255. Using histogram equalization, an improvement in the contrast of an image is acquired by adjusting the intensity of every gray level of the image [16]. The cumulative distribution function of a pixel is given by Eq.(1).

$$F(x) = P_r[X \le x] = \alpha(1) \tag{1}$$

The cumulative distribution function is the probability where a variable takes a value less than or equal to x. The original image with its histogram equalized image is shown in Fig. 3.

Fig. 3: (a) Original image (b) Histogram equalized image

4.2. Binarization

Binarization is used to convert an image from grey scale to binary. For binarizing an image, global threshold technique is used in which a threshold value is chosen in the range of [0,1] which minimizes the inter-class variance of the black and white pixels. The pixels lower than this threshold value are represented with white color and above are represented as black. The threshold value used in proposed method is 0.9. Mathematically, consider a grayscale image in which $g(x, y) \in [0, 255]$ be the intensity of a pixel at location (x, y). In global thresholding techniques, Eq. (2) is used to compute a threshold value for each pixel [17].

$$o(x, y) = \begin{cases} 0 & if\, g(x, y) \le level(0.9) \\ 1, & otherwise \end{cases} \tag{2}$$

In this way the foreground image is well separated from the background. The result after binarizing an image is shown in Fig. 4. It is desirable to enhance the low quality fingerprint image using morphological processing with region division.

Fig. 4: (a) Original image (b) binarized image

5.   Image Enhancement by Proposed Algorithm

Recently the technique used for low quality fingerprint image enhancement is by using stochastic resonance. Ryu et al. [5] proposed the model by adding an appropriate amount of noise prior to Gaussian noise to the original signal. However, Gabor filters used for enhancement did not recover the fingerprint ridge pattern as local ridge direction or distance of the ridge flow are not visible in low-quality images. Our proposed method focuses on morphological closing operation applied on binary image for improving the ridge structure of fingerprint image so that it is used for genuine feature extraction. After enhancing the low quality image by increasing its contrast enhancement and converting it into binary image, it is first inverted and then morphological operations are applied with region division as shown in Fig. 5.
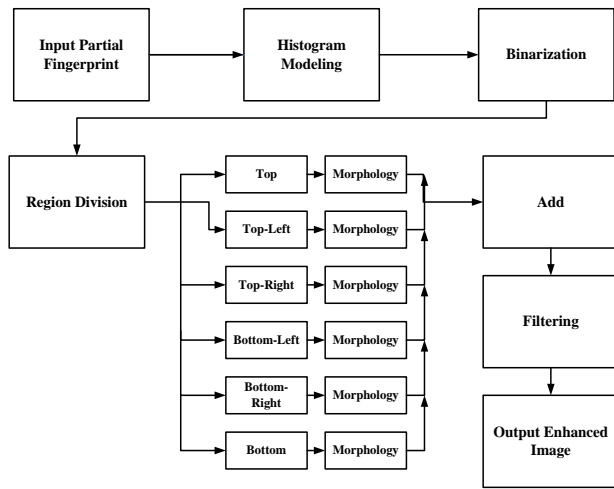
Fig. 5:   Block diagram of proposed algorithm for image enhancement using morphological transform and region division technique.

5.1   Morphological Approach

Morphology is a non-linear or geometric analysis theory of image processing [4].   The morphological operations are found appropriate as these are used to enhance noisy images, boundary detection, noise removal and image segmentation. The major advantages of morphological approaches are direct geometrical interpretation, simplicity, ease of operation and efficiency [4]. By applying morphological approach like closing with structuring element plays a vital role to examine the input image. SE is a small matrix of pixels each with a value of zero or one. In proposed model the structuring element "line" is used with radius r and angle θ for fingerprint image knowing the fact that ridges are lying at a certain angle. Therefore, broken ridges are connected well when the structuring element 'line' is used with appropriate radius r and angle θ. In fingerprint image enhancement the dilation and erosion processes are

usually used using same or different structuring element [3]. In this paper morphological closing is used which is defined by Eq. (3) by set A with structuring element B such as [14] :

$$A \bullet B \ = \ (A \oplus B) \ominus B \qquad (3)$$

Therefore, the closing of A by B is the dilation of A by B, followed by the erosion of the result by B. It smoothes the image, joins narrow breaks and fill holes smaller than structuring element shown in Fig. 6.
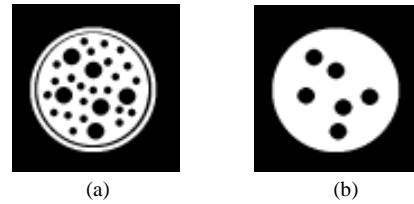
Fig. 6:   (a) Original image (b) Result after applying 'closing'

However, due to different orientation of ridges and valleys in a fingerprint image, it is divided into sub images and then morphological operations are performed on each sub image with structuring element. It joins the broken ridges in a best possible manner. The approach to split an image into parts and applying structuring element on each part separately is known as region division.

5.2   Region Division

The splitting up of an image into various sub images is known as region division. It divides the image in to number of sub images as shown in Fig. 7(a). In this proposed method, image is divided in to six regions namely top, top-left, top-right, bottom-left, bottom-right and finally the bottom portion. After applying morphological operations on each sub-image with suitable structuring element, the sub fingerprint images are thus enhanced. The resultant sub-images after enhancement from top to bottom are shown in Fig. 7(b). Treating each sub image and enhancing them individually, the image is re-joined again using basic Add operation shown in Fig.7(c). The Add operation is defined by having an input image I which is divided into six divisions described above is re-joined together by Eq. (4) :

$$I_{image} \ = \ top + top\ left + top\ right +$$
$$bottom\ left + bottom\ right + bottom \qquad (4)$$

This approach is useful for enhancing details in the presence of the ridge structure.

5.3   Proposed Algorithm

The proposed algorithm consists of following steps for enhancement with region division:

1.   Consider an input image of low quality of size $r \times c$ where r denotes the no of rows and c specifies the no of columns.

2. The input image after undergone contrast enhancement and binarization is inverted by simple negation operator.

3. The inverted input image is decomposed into six regions. The first region prior the top region is divided into $[(1: r/8): (1: c)]$ size.

4. Morphological closing is applied with structuring element 'line' of suitable radius r and angle θ. In proposed approach, the radius 7 and angle 30 is taken empirically for top region.

5. Similarly, the top left with size $[(\frac{r}{8} + 1): \frac{r}{2}): (1: \frac{c}{2})]$, top right $[(\frac{r}{8} + 1: \frac{r}{2} + 1): (\frac{c}{2} + 1: c)]$, bottom left $[(\frac{r}{2} + 1: \frac{7r}{8}): (1: \frac{c}{2} + 1)]$, bottom right $[(\frac{r}{2} + 1: \frac{7r}{8} + 1): (\frac{c}{2} + 1: c)]$ and bottom $[(\frac{7r}{8} + 1: 1: c)]$ is divided and step 4 is repeated every time till it reaches the last pixel value of an image. In this way, only the pixel value r and c pixels are duplicated while merging/addition of an image using region division technique.

6. Finally, the sub-images are re-joined to reconstruct the image by Add operation.

5.4   Post-Processing

In proposed method, the enhanced fingerprint image is finally passed through median filter in two dimensions of window size 3 x 3 in order to remove background noise just in case if it is introduced during filling up the gap in ridge/valley pattern. In median filtering the input pixel is replaced by the median of the pixels contained in window around the pixels [1] by Eq. (5).

$$V(m, n) = median\{(m - k), (n - 1), (k, 1) < W\} \quad (5)$$

Where W is a chosen window, m and n are the no. of rows and columns in an image, k is the no. of iteration level of the window size of a median filter. The final result after filtration is shown in Fig. 8. The window size chosen in proposed algorithm is 3×3.

6.   Experimental Results

In order to evaluate the performance of the proposed method, various low quality fingerprint images are collected from database FVC-2002. The proposed algorithm is applied on low quality fingerprint images which gives satisfactory results. The output of proposed algorithm is shown in Fig. 7 (a), (b) and (c). The algorithm is applied on 14 images from FVC-2002. Broken ridges gaps of low quality fingerprint images are shown in rectangle in Fig. 9 (a), (c), (e), (g), (i), (k), (m), (o), (q), (s), (u), (w) and (y). The resultant connected ridges are shown in corresponding rectangle of Fig. 10 (b), (d), (f), (h), (j), (l), (n), (p), (r), (t), (v), (x) and (z). The fingerprint images by proposed method are compared with ground truth on the basis of different quantitative measures such as correlation quality-score, accuracy and equal error rate (EER).
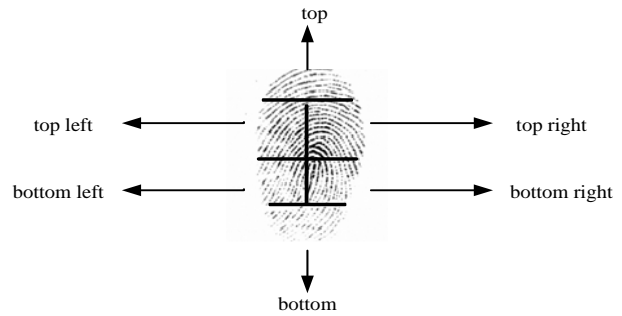

Fig. 7:   (a) Concept of region division.
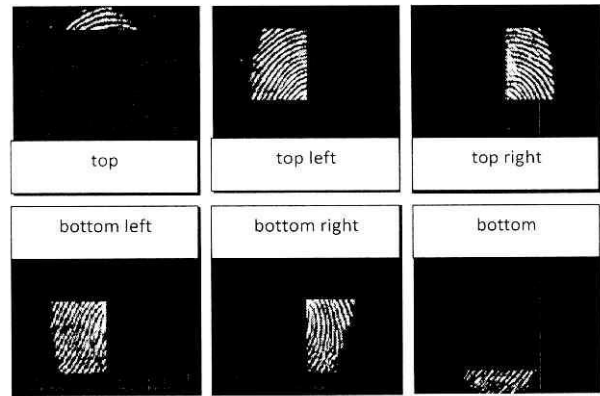

Fig. 7:   (b) Enhancement using proposed algorithm.

Fig. 7:   (c) Enhanced image after re-joining sub-regions.

Fig. 8:   Resultant image after post-processing.

6.1.   Evaluation of Correlation Quality-Score

The correlation used in proposed method is Pearson product-moment correlation coefficient. Given a set of observations (x_1, y_1), (x_2, y_2),........., (x_n, y_n), correlation co-efficient is given by Eq. (6) [15].

$$r = \frac{1}{n-1}\Sigma(\frac{x-\bar{x}}{s_x})(\frac{y-\bar{y}}{s_y}) \quad (6)$$

where $\bar{x}$ is the sum of pixel values divided by no. of items in the sample computed by Eq. (7).

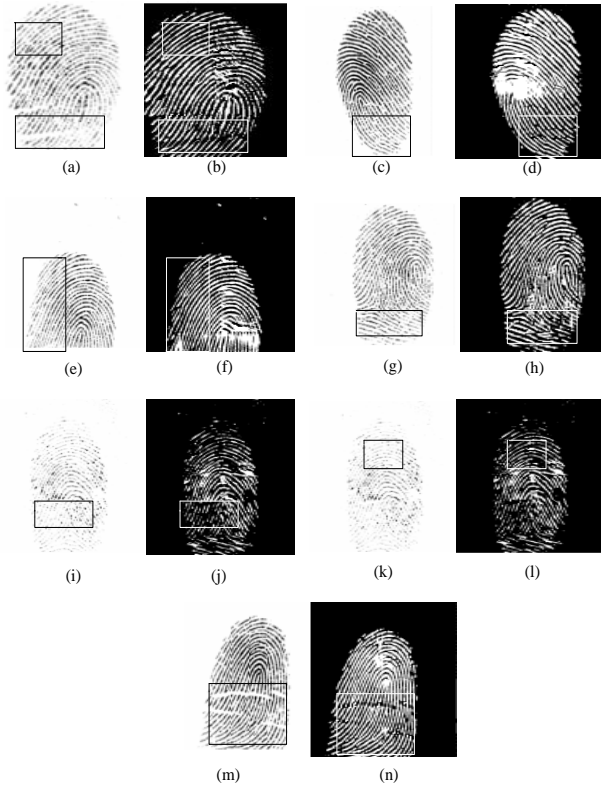$$\bar{x} = \frac{x_1 + x_2 .... + x_n}{n} \quad (7)$$

Fig. 9: Results of proposed algorithm on test images.

and s_n is the standard deviation of the sample given by Eq. (8).

$$s_n = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_{i-}\bar{x})} \tag{8}$$

Where N stands for the size of the sample. The coefficient correlation ranges from 1 to -1. The higher the coefficient, the more similar two variables are, and the lower the coefficient, the more dissimilarities are obtained. The average correlation quality-score rate of the proposed

method is found to be 87.88%. The score is then compared with other algorithms in the literature and is tabulated in Table 1. Raffaele et al. [14] has more than half false minutiae and 28% less missed minutiae but the system is based on manual markup. The proposed algorithm is purely automated. The score is usually a value between 1 and 100 where 100 being the best quality and 1 stands for poor quality.

6.2. Evaluation of Accuracy

In this section, the accuracy of the proposed method is evaluated. The percentage accuracy is a measure of square of the correlation coefficient given by Eq. (9) [18].

$$Percentage\ Accuracy = (correlation\ coefficient)^2 \times 100 \tag{9}$$

The percentage accuracy of the proposed method is found to be 76.16%. The proposed algorithm is then compared
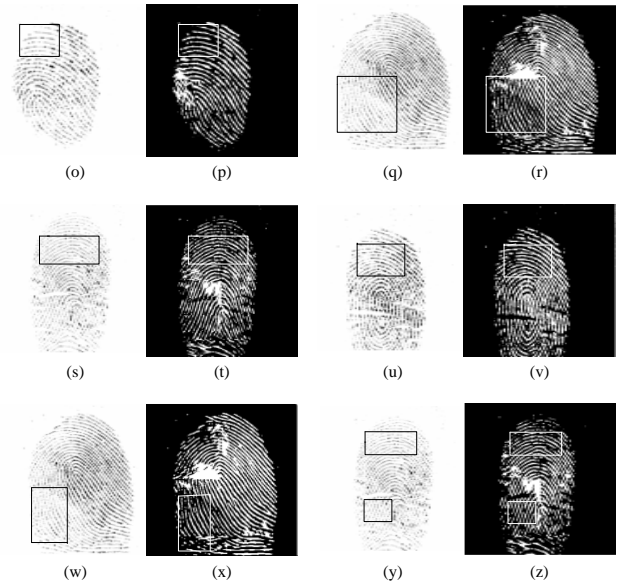

Fig. 10: Results of proposed algorithm on test images.

Table 1: Comparison of correlation quality score of proposed algorithm with other methods

Algorithm	No. of Test Images & DataBase	Approach	Correlation Quality Score	Comments
Romdhare et al. [13]	07/ Partial images of size 235 x 182	Diffusion tensor approach	PSNR 12.67, MSSIM 0.64, score 62.5%	Image size restriction
Raffaele et al [14]	18 / NIST DB27	Contextual based Gabor Filter technique	50% False minutiae, 28% missed minutiae.	Manual markup is needed
Proposed Algorithm	14 / FVC-2002	Morphological Closing with SE line with region division	87.88%	Fully automated

Table 2: Comparison of accuracy of proposed algorithm with other existing methods in the literature

Algorithm	No of Test Images & DataBase	Approach	Accuracy	Limitations
Deepika et al [8]	08/ FVC2002	Wavelet based normalization is used for illumination.	Accuracy 96.98%	Edge and contrast enhancement.
Proposed Algorithm	14/ FVC2002	Morphological Closing with SE line with region division	Accuracy 76.16%	Enhanced edge contrast and also joined broken ridges in an image

with other algorithms in the literature and is tabulated in Table 2. Deepika et al. [8] enhanced only the contrast and edge of a fingerprint image using wavelet transform with an accuracy of 96.98%. These two parameters can be enhanced by using histogram equalization as well. The method proposed has enhanced not only the edge and contrast of a fingerprint image but it also has re-joined broken ridges by filling gaps between them with overall accuracy of 76.16%.

6.3 Evaluation of Equal Error Rate (EER)

EER is defined when False Acceptance Rate(FAR) is equal to the False Rejection Rate(FRR). The lower the value of equal error rate, the higher the accuracy of the biometric system. The EER of the proposed method is 3.16%. The comparison with the literature review deduced that the proposed method has promising performance than other methods for enhancement. The comparison is tabulated in Table 3.

Table 3: Comparison of EER of proposed algorithm with other Algorithms in the literature

Algorithm	No of Test Images& DataBase	Approach	Performance Evaluation	Comments
Das et al [10]	08 / FVC-2002 DB 1a with image size 388 x 374 & 296 x 560 for data base FVC- 2002 DB2a	Distance based hashing algorithm.	EER 2.27% for database FVC-2002 DB1a and 3.79% for FVC-2002 DB2a	Image size restricted to 388 x 374 for data base FVC-2002 DB1a and 296 x 560 for data base FVC-2002 DB2a
Li et al [12]	08 / FVC-2000, FVC-2002 and FVC-2004	Free-alignment cryptosystem based on fixed-length bit-string representation	EER 0.59% if 1 and 2 images from data base are selected EER 10.38% when random fingerprint image from each data base	Outperforms for first two images for they having less variation from each data set and shows worse results for random selection of image.
Malathai et al [15]	06 / NIST SD-30	Fusion technique based on SIFT and pore.	Accuracy 98.14% with 60% image size EER 4.71%	Image size of 60% is used.
Proposed Method	14/ FVC2002	Morphological Closing with SE line with region division	EER 3.16%	Fully Automated system applied on binary images. No image size restriction. Outperforms for random selection of images from data set.

7. Conclusion

The proposed algorithm for low quality fingerprint image enhancement with region division relies on fingerprint having certain natural imperfections such as noise and broken ridges. The region division technique divided the image into six regions. Morphological transform with SE "line" having appropriate angle θ and radius r has connected or filled the gaps between the broken ridges in each region owing to the orientation of the ridges. The experimental results show that the proposed method increased the contrast, reduced the noise and morphological transform with region division is used to fill the gaps between the broken ridges. The resultant enhanced images by proposed algorithm can be directly used for feature extraction and minutiae matching. Simulation on 14 fingerprint images of various types i.e., dry sample, severe wrinkles or cracks from FVC-2002 database were tested. The morphological transform with region division outperforms for almost all type of low quality images having excessive broken ridges. In terms of matching performance for low quality images, the equal error rate is improved in comparison with existing techniques.

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