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Spatial Filtering and Morphological Operation as Pre-Processing Steps in Fingerprint Feature Extraction

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ABSTRACT
Extracting features from a fingerprint image relies mainly on the pre-processing stages the fingerprint has gone through. When the fingerprint image that has been captured is good enough then the final matching stage will produce a satisfying output. But many a times the image which is captured suffers from contact problems such as non-uniform contact, inconsistent contact and irreproducible contact.Because of such adverse and unpredictable image acquisition situations, a biometric system's (Fingerprint Recognition System) performance suffers from random false rejects/accepts. Hence the need for the pre-processing of an image becomes necessary. In this paper, pre-processing steps of spatial filtering and morphological operation in addition to Gabor filtering are introduced and comparative analyses of the three are done in MATLAB. It has been found that there is a significant removal of false minutiae in the step of minutiae extraction, if spatial or morphological filtering methods are introduced prior to Gabor filtering.

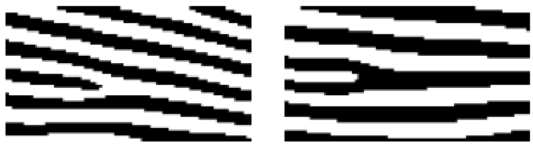
General Terms
Fingerprint recognition system, pre-processing, feature extraction, minutiae based approach

Keywords
Fingerprint, minutiae, ridge end, bifurcation, Gabor filtering, spatial filtering, morphological operator

1. INTRODUCTION
Biometric field is mainly concerned with the study of behavioural and psychological attributes of a person which helps in the identification of an individual among a group of others. Fingerprint is one such biometric feature which stands aloof from the other biometrics, since it remains unique for a particular individual and has also been proved to be more accurate [1]. Thus fingerprint serves to be the most acceptable, popular and a matured biometric trait.

The impression or mark which is created by a person's fingertip is called a fingerprint. Ridges and valleys are the two patterns found in a fingerprint. The ridges are the dark pixel curved lines while valleys are being enclosed by the ridge lines. The certain uniqueness in the alignment, relationship, pattern and characteristics of these ridges and valleys plays a major role in the fingerprint recognition algorithm. Therefore an enhancement process, which clearly defines the ridge structures, is needed so that the performance of the features which are the minutiae remains robust with respect to the fingerprint images.

Most of the fingerprint recognition systems are based on the identification of the different minutiae which are present on the fingerprint image. Minutiae (or Galton's characteristic as called) are the local discontinuities which appear across a ridgeline on the surface of the fingerprint. Each minutia has got its own structure as it is formed by the spreading of the ridge line throughout the surface. If the ridge line comes to an end, then that minutia is termed as termination and if the ridgeline branch itself into two ridgelines it is called bifurcation, this is shown in fig 1. Crossovers are the ones where two ridgelines cross each other. Basically in the feature extraction algorithm through minutiae detection, termination and bifurcation minutiae points are considered [2].



a) ridge ending **b) bifurcation**

Fig 1 A ridge ending and a bifurcation shown

The feature extraction techniques in the fingerprint recognition system are of the following types.

Minutiae Based Technique: Most of the fingerprint recognition systems are based on the extraction of local features, minutiae is one of them. There are almost 18 different types of them, out of which the most commonly considered ones are the ridge ending (terminations) and bifurcations[3].Matching is done if these features characteristics such as positions, orientations and the types match in both the input test image and the stored database of the images. This approach is presently the backbone of many of the research works.

Pattern Matching or Ridge Feature Based Techniques: This technique includes content based image retrieval problems. In such feature extraction techniques, the whole pattern of the ridge and the series of ridges are considered [4]. The minutiae may be affected by wear and tear, but this technique does not depend on these discrete minutiae points and considers on the ridge as a whole. But its disadvantage is that this method is sensitive to the proper placement of the finger and requires large storage for the templates.

Correlation Based Technique: The same finger appears to be different because of non-linear distortion. The local or block-wise correlation techniques check into account this problem. Varying skin condition and finger pressure can cause the image brightness, contrast and ridge thickness to vary. The use of correlation technique compensates for these problems [5].

Image Based Techniques: These techniques are based on the extraction of the global features of the whole fingerprint [6]. This technique is a newly emerging one with scope of further improvement.

Fingerprint recognition system (FRS) for the minutiae based approach, usually consists of the following three parts:

a. Image pre-processing
b. Feature extraction and
c. Fingerprint matching (verification and identification).

a. Pre-processing is a very important step for FRS since it is used for noise reduction and increasing the contrast between the ridges and the valleys. Thus it improves the image data and supresses the unwanted distortions

b. Feature extraction step involves refining of the thinned image, detecting the minutiae points and then extracting features from image. The most popular technique of minutiae detection is through the use of the crossing numbers approach [7].

c. The matching stage can be any of the two different methods, i.e. verification and identification. Verification is the process where the individual fingerprint is matched by comparing it with one specific fingerprint stored on the database against that particular individual. But in case of identification, the matching of a fingerprint of a person is carried out with all the fingerprints stored in the database of different features to find out the best match.

Enhancement

Enhancement can result in accentuation, or sharpening of the minutiae, in addition to the reduction or elimination of noise and other undesirable discontinuities. Thus the enhancement stage plays a major role in the pre-processing step of a fingerprint recognition system. The enhanced image should therefore try to retain as many minutiae as possible, at the same time suppressing the misleading patterns such as noise, spurs or breaks.

In this work a comparative analysis of the minutiae extracted from the three methods i.e. Gabor filtering and addition of other two pre-processing steps which are spatial filtering and morphological operation to Gabor filtering has been done. The paper is organised as follows: Section 2 covers some pre-processing works. Here, mainly the work done by Hong et al in the fingerprint enhancement process has been considered as required in the proposed method. Section 3 presents the proposed method using the spatial filtering and morphological operation for pre-processing. In section 4, the minutiae extraction process has been discussed. This is followed by the next section i.e. section 5, where we show the results of the comparative analysis. Finally in Section 6, a conclusion has been drawn based on the results obtained and future scope of this work is mentioned.

2. PREVIOUS WORK ON PRE-PROCESSING

Among the many works done in the field of fingerprint enhancement for removing the noise and the other misleading effects, a few of them are discussed below.

A method of Directional Median Filter has been proposed for removing this noise and spurious signals [8].

Another improved method over [8] that has been proposed is Directional Weighted Median Filter (DWMF) [9]. Here, a new impulse detector, which is based on the differences between the current pixel and its neighbours aligned with four main directions, has been proposed in [9].

Another paper is the one where Dr E.Chandra applied Median filtering technique [10], as a pre-processing step in order to produce the noise free image. For this, initially the histogram on 256 gray scale finger print image with the default threshold value is applied to obtain the histogram-equalized image. Next Binarization step is performed on the histogram equalised image. Finally the binarised image is filtered with the median filter so as to get a noise free image. Here, a comparative analysis of the median filtered image and the original image is done and the quality of the filtered image is analysed with a Statistical-Correlation tool.

The work by Shlomo Greenberg [11], proposes two methods for removing noise in a fingerprint image. The first one is carried out using histogram equalization, Wiener filtering, binarization and thinning. The second method uses a unique anisotropic filter for direct gray-scale enhancement. Both methods show some improvement in the minutiae detection process in terms of time required and efficiency.

In [12], Bansal et al have proposed that the morphological step is necessary for removing the spurious minutiae in thinned images. The existence of some isolated regions and misconnections in the binarised image leads to the formation of the spurious minutiae. The minutiae extraction algorithm is based on morphological Hit or Miss Transform which has been employed in the paper.

In [13], initially spatial domain operators are applied for contrast enhancement. Gaussian linear filtering is then performed for removing noise by the convolution and correlation operations. Next, morphological structuring element is applied to link the disconnected ridges. Hence, fingerprint enhancement is a better one, since the broken ridges are connected which would have otherwise contributed in the reduction of False Acceptance Rate.

2.1 Gabor Filtering For Enhancement:

Among the many works done in pre-processing, the work by Hong et al [14], which is based on the convolution of the image with Gabor filters tuned to the local ridge orientation and ridge frequency, has been used as the model reference for performing the comparative study. The Gabor filter based enhancement algorithm comprises of the following stages- normalization, ridge orientation estimation, ridge frequency estimation and filtering.

2.1.1 Normalisation

An image may be imperfect because of adverse image acquisition situations like non uniform contact, non-uniform ink density etc. A fingerprint image may then exhibit distorted levels of variation in grey-level values along the ridges. If such an image is passed through the normalisation step, then there is a considerable reduction of the effect of these variations.

Let $I(i,j)$represent the grey-level value at pixel$(i,j)$and $N(i,j)$represent the normalized grey-level value at pixel (i,j). The normalized image is defined as:

$$N(i,j) = \begin{cases} M_0 + \sqrt{\dfrac{V_0(I(i,j)-M)^2}{V}}, \text{if } I(i,j) > M \\ M_0 - \sqrt{\dfrac{V_0(I(i,j)-M)^2}{V}}, \text{otherwise} \end{cases}$$

Where *M* and *V* are the estimated mean and variance of $I(i,j)$respectively, and M_0 and V_0 are the desired mean and variance values, respectively.

2.1.2 Local orientation estimation
An orientation image is then calculated, which is a matrix of direction vectors representing the ridge orientation at each location in the image.

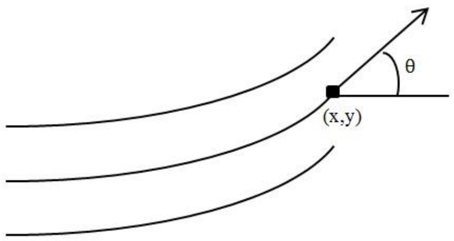


Fig 2: The orientation of a ridge pixel in a fingerprint

The final smoothed orientation field O at pixel is defined as:

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

where

$$\emptyset'_x(i,j) = \sum_{u=-\frac{w}{2}}^{\frac{w}{2}} \sum_{v=-\frac{w}{2}}^{\frac{w}{2}} G(u,v)\emptyset_x(i-uw)(j-vw),$$

$$\emptyset'_y(i,j) = \sum_{u=-\frac{w}{2}}^{\frac{w}{2}} \sum_{v=-\frac{w}{2}}^{\frac{w}{2}} G(u,v)\emptyset_y(i-uw)(j-vw),$$

And G is a Gaussian low-pass filter of size w x w.

2.1.3 Local frequency image
The next step is determination of the ridge frequency. This is done by dividing the input image into a certain block size. Here the block size is of 16x16. Then the gray level values of all the pixels inside the block are projected to the local ridge orientation since it forms a sinusoidal shaped wave.

Once these two parameters are found out the next step in the process is Gabor Filtering.

2.1.4 Gabor filtering
The parameters of ridge orientation and frequency are used for constructing even symmetric Gabor filters. The even symmetric Gabor filter is the real function, which is a cosine wave modulated by a Gaussian.

$$G(x,y;\theta,f) = \exp\left\{\frac{1}{2}\left(\frac{{x_\theta}^2}{{\sigma_x}^2} + \frac{{y_\theta}^2}{{\sigma_y}^2}\right)\right\}\cos(2\pi f x_\theta)$$

$$x_\theta = x cos\theta + y sin\theta$$

$$y_\theta = -x sin\theta + y cos\theta$$

where θ is the orientation of the Gabor filter, f is the frequency of the cosine wave, $\sigma_x$and $\sigma_y$are the standard deviations of the Gaussian envelope along the *x* and *y* axes, respectively, and x_θ and y_θ define the *x* and *y* axes of the filter coordinate frame, respectively.

The Gabor filter is applied to the fingerprint image by spatially convolving the image with the filter. The convolution of a pixel (i,j) in the image requires the corresponding orientation value *O (i,j)* and ridge frequency value *F(i,j)* of that pixel. Hence, the application of the Gabor filter *G* to obtain the enhanced image *E* is performed as follows:

$$\sum_{u=-w_x/2}^{w_x/2} \sum_{v=-w_y/2}^{w_y/2} G(u,v;O(i,j),F(i,j))N(i-u,j-v)$$

Where *O* is the orientation image, *F* is the ridge frequency image, *N* is the normalized fingerprint image, and w_x and $w_y$are the width and height of the Gabor filter mask, respectively.

The effect is that the filter enhances the ridges oriented in the direction of the local orientation, and decreases anything oriented differently. Hence, the filter increases the contrast between the foreground ridges and the background, whilst effectively reducing noise.

3. PROPOSED METHOD ON PRE-PROCESSING
Addition of some other pre-processing steps in the method of Gabor based enhancement is done for extraction of minutiae. The two pre-processing operations that have been added to the Gabor enhancement are spatial filtering and morphological operation[12,13].

3.1 Spatial Filtering
The first method consists of addition of spatial filters which has shown to produce faithful minutiae [15]. Blurring and noise reduction can be done by the use of smoothing spatial filters. Blurring is used in pre-processing tasks for removing small details from an image prior to large object extraction. Here, it can be used for removing the small dots and structures which are just acting as noise in the fingerprint image. An order statistics median filter has been used for this purpose.

Order statistics filter are the non-linear filters, whose response is based on the ranking of the pixels contained in the image area encompassed by the filter, and then replacing the value of the centre pixel with the value determined by the ranking result.

1. Min and Max Filter

The smallest and the largest value within the pixel values are selected by the minimum and maximum filter. In this process the maximum and minimum intensity values are found within a window of certain pixels. The output remains unchanged when the central pixel lies within the intensity range of its neighbors. If the central pixel is greater than the maximum value within that window, then it is set to the maximum value and if it is less than the minimum value than it takes the minimum value to itself.

2. Median Filter

The nonlinear filter used for removing impulsive noise from an image is the median filter. In this filter, ranking is done on the pixels within a window based on intensity values and the central pixel replaces itself with the value which is mid-way in ranking.

3. Midpoint Filter

The midpoint filter is used for blurring the image by replacing it with the average of the highest intensity pixel and the lowest intensity pixel within the specific window.

Midpoint = (darkest+lightest)/2

Median filter is the best known filter in this category.

Individual noise spikes hardly influence the median values in a neighbourhood. Thus the median filtering removes the impulse noise quite well.

Considering frequency domain filtering, the effect of LPF applied to an image is to blur (smooth) it. Similar smoothing effect can be to an image is to blur (smooth) it. Similar smoothing effect can be achieved by using spatial filters (spatial masks, kernels, templates, or windows).

The operation on an image where each pixel value *I (u,v)* is changed by a function of the intensities of the pixels in a neighbourhood of *(u,v)* is performed by a spatial filter.

Assuming a 3 x 3 neighbourhood, at any point (x, y) in the image, the response of the spatial filter is response of the spatial filter is:

$$g(x,y) = w(-1,-1)f(x-1,y-1) + w(-1,0)f(x-1,y) + w(0,0)f(x,y) \ldots w(1,1) + f(x+1,y+1)$$

3.2 Morphological Operators

The second pre-processing operation used here is the combination of morphological operators namely erosion and dilation [16]. Morphological operators can be used for extracting the image components and noise reduction [17]. Erosion as the name suggests is a shrinking or thinning operation whereas Dilation thickens or grows objects in a binary image. Erosion (or thinning) and Dilation (or thickening) are the two morphological operators that have been used in the pre-processing step are discussed [12,13].

The structuring element controls the amount of thinning or thickening of the image. Erosion can be used for removing spurious noise signals appearing in an image in the form of small dots curves or lines. Dilation is used for bridging gaps and also for joining broken segments.

Mathematically, the process of erosion and/or dilation can be thought as the union and/or intersection of an image with a translated shape called the structuring element.

Let A: $z^2 \rightarrow z$ be an image and B: $z^2 \rightarrow z$ be a structuring element. The erosion of A by B denoted by (AΘB), is expressed as

$(A\Theta B) = \{z \mid (B)_z \cap A^C \neq \emptyset \}$

The dilation of A by B, is denoted by (A⊕B), and is expressed as

$(A \oplus B) = \{z \mid (B)z \cap A \neq \emptyset \}$

Here a square structuring element of size 3x3 is taken and the following steps are performed in sequence.

1. Erosion of the image, followed by dilation.
2. Dilation of the resulting image, followed by erosion.

4. MINUTIAE EXTRACTION

Once the Gabor filtering has been done to enhance the ridge pattern, then some more steps are performed to finally extract the minutiae.

Binarization:
Firstly, a Binarization of the image obtained is done keeping the threshold as zero. A value of represents that the pixel is white and a value of zero indicate the pixel to be black. A threshold value is set for each pixel in the image. Those pixel values which are smaller than the threshold is set to zero and the pixel values which are greater than the threshold is set to one. The image produced is in binary form.

Thinning:
Next, thinning operation is done on the binary image obtained from the previous step. Thinned ridge lines are obtained using morphological thinning operator bwmorph.

Finally minutiae extraction is done on the thinned image. This process is done by using a 3x3 window to examine the local neighbourhood of each ridge pixel in the image. The minutiae extraction is based on crossing number concept.

Minutiae extraction based on crossing number:
Following the image enhancement step, one needs to reliably extract the minutiae present in a fingerprint. A method which is most commonly used for this purpose is the crossing number concept. This method uses the skeleton image of the original image where the ridge flow pattern is eight-connected. A 3x3 window is used for scanning the local neighbourhood of each pixel in the image for extracting the minutiae. The CN value is then computed, which is defined as half the sum of the differences between pairs of adjacent pixels in the eight neighbourhoods.

The crossing number for a ridge pixel P is given

$$CN = 0.5 \sum_{i=1}^{8} |P_i - P_{i+1}|$$

Where P_i is the pixel value in the neighborhood of P. For a pixel P, its eight neighboring pixels are scanned in an anti-clockwise direction as follows:

P_4	P_3	P_2
P_5	P	P_1
P_6	P_7	P_8

After the CN for a ridge pixel has been computed, the pixel can then be classified according to the property of its CN value. As shown in Figure, a ridge pixel with a CN of one corresponds to a ridge ending, and a CN of three corresponds to a bifurcation.

Table1: Table Shows the Properties of Different Crossing Numbers

Crossing number	Property
0	Isolated point
1	Ridge ending point

2	Continuous ridge point
3	Bifurcation point
4	Cross over point

5. RESULTS AND DISCUSSIONS

5.1 Feature extraction after Hong et all method of enhancement

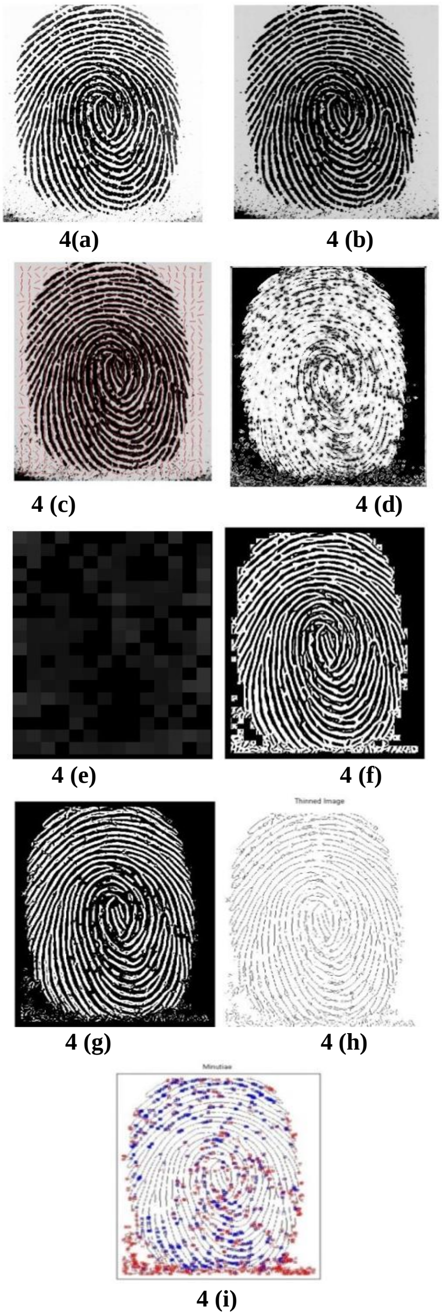


Fig 4:a-i shows the various images in the following sequence-a)original image, b)Normalised original image, c) Local oriented image, d) Reliability of orientations, e) Frequency data, f) Binarised image, g)Masked binarised image, h) Thinned image, i)Minutiae detected image

5.2 Spatial Smoothing Filters Characteristics

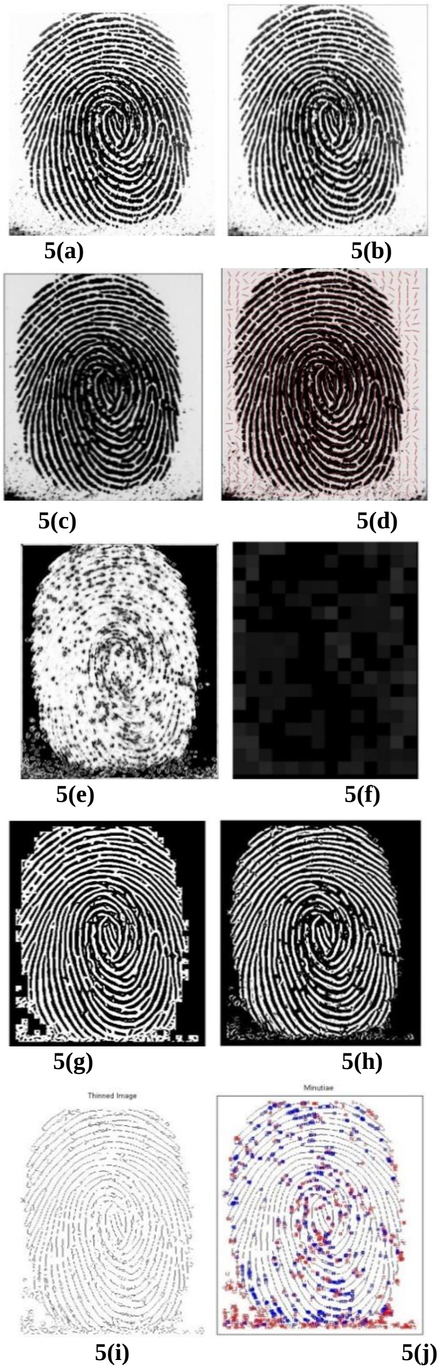


Fig 5:a-j shows the various image in the following sequence-a)Original image, b)Image obtained after spatial filtering c)Normalised original image, d) Local oriented image, e) Reliability of orientations, f) Frequency data, g) Binarised image, h)Masked binarised image, i) Thinned image, j)Minutiae detected image

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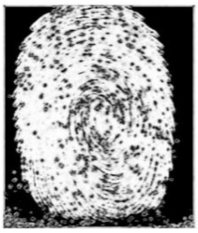
5.3 Morphological filtering applied as a pre-processing step prior to Gabor filtering gives the following results

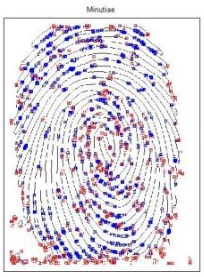

6(a) **6(b)**


6(c) **6(d)**




6(e) **6(f)**


6(g) **6(h)**



e

6(i) **6(j)**

Fig 6:a-j shows the various image in the following sequence-a)Original image, b)Image obtained after morphological operation c)Normalised original image, d) Local oriented image, e) Reliability of orientations, f) Frequency data, g) Binarised image, h)Masked binarised image, i) Thinned image, j)Minutiae detected image

The testing is done on all of the fingerprints available in the IIITD database i.e. 150, which is comprised of 15 persons with all of their 10 fingers contributing to a total of 150. However,here results of the comparative study of 5 persons are presented. The database comprises of a single persons' ten fingers which are marked as LI(Left Index),LR(Left Ring),LM(Left Middle),LS(Left Small),LT(Left Thumb), RI(Right Index),RR(Right Ring),RM(Right Middle),RS(Right Small) and RT(Right Thumb) respectively.

Two tables showing the number of minutiae extracted after performing Gabor filtering, spatial filtering prior to Gabor filtering and morphological operation in addition to Gabor filtering are made.

Table 1. Table shows the number of minutiae extracted from the different processes against its corresponding finger number in the database

Fingerprint no	Gabor	Spatial	Morphological
1_LI	133	120	120
2_LI	129	131	126
3_LI	132	121	120
4_LI	123	131	135
5_LI	112	120	118
1_LR	149	149	149
2_LR	102	104	100
3_LR	208	227	206
4_LR	152	165	156
5_LR	142	137	135
1_LM	148	139	137
2_LM	108	107	98
3_LM	176	173	169
4_LM	107	106	107
5_LM	102	119	124
1_LS	174	175	165
2_LS	174	160	168
3_LS	167	164	169
4_LS	159	154	152
5_LS	149	137	129
1_LT	136	145	97
2_LT	109	112	108
3_LT	130	135	122
4_LT	126	121	110
5_LT	132	120	125

Table 2. Table shows the minutiae extracted for the different pre-processing steps against the right fingerprint database

Fingerprint no	Gabor	Spatial	Morphological
1_RI	125	119	127
2_RI	159	151	94
3_RI	118	123	107
4_RI	117	114	111
5_RI	120	120	105
1_RR	163	166	100
2_RR	136	139	134
3_RR	157	153	109
4_RR	148	152	90
5_RR	116	114	112
1_RM	149	157	111

2_RM	125	132	129
3_RM	130	122	126
4_RM	126	130	130
5_RM	121	122	119
1_RS	111	129	117
2_RS	193	174	181
3_RS	126	123	116
4_RS	125	136	75
5_RS	109	113	108
1_RT	151	154	144
2_RT	135	143	138
3_RT	111	105	103
4_RT	144	152	101
5_RT	106	109	95

A comparative analysis of the three shows that Gabor filtering produces more number of minutiae than the other two. It is seen that in many of the cases, morphological operation produces the minutiae near the range that generally a good fingerprint has (80-100) with the exception in cases where noise contributes to additional spurious minutiae. To name a few from the IIIT Database, where these changes are prominent are the fingerprints numbered 3RT, 4RT, 5RT, 2RI, 3RI, 1RR, 4RR and 4RS. Considering fingerprint number 3RT, addition of morphological operation as a pre-processing step produces 103, compared to spatial filtering's 105 and Gabor enhancement's 111. Similar are the cases in fingerprints numbered 4RT, 5RT,2RI,3RI,1RR,4RR,4RS where morphological results in 102, 95, 94, 107, 100, 90 and 75; spatial filtering results in 152, 109, 151, 123, 166, 152, 136; and Gabor filtering produces 144, 106, 159, 118, 163, 148 and 125 respectively. But these comparisons are based on the fact that the fingerprints are of good quality. In the database, some images such as 5LI, 4LR, 5LM, 2RT are of poor quality which have non-uniform contact or are of some dried finger. In such fingerprints, variation of the results takes place. To cite a few, let us consider the above mentioned fingerprints where morphological operation produces 198, 156, 124 and 138; spatial filtering produces 120, 165, 119, 143; and Gabor filtering produces 112, 152, 102 and 135 number of minutiae in fingerprints numbered 5LI, 4LR, 5LM and 2RT. As can be seen here, the outcome of morphological operation is not as expected. This is mainly because the fingerprints are very much corrupted since noise in the form of clutter noise and background noise may also come into being. This form of clutter noise appears in an image during the process of scanning. Background noise comes in the form of uneven contrast which is shown through effects and background spots, etc. Thus this is approach of pre-processing is applicable in fingerprints which are not much affected by noise so as to produce fruitful results.

6. CONCLUSION AND FUTURE SCOPES

It has been found that the morphological operators' serves as the best pre-processing step compared to the other two methods if the fingerprints are less affected by noise. Hence, these non-linear morphological operators are more suitable for shape analysis as it helps to preserve and detect the geometric structure of objects. Another advantage of morphological operation is its speed and simplicity of implication. Thus for a better image enhancement process, the above describes steps must be followed sequentially. This will produce an image where the extraction of minutiae becomes easier. However certain limitations do exist, we assume that the quality of the captured image is good enough. In such cases, the proposed method fails and the minutiae extracted after morphological operation are more in number than the other two, contributing to more number of spurious minutiae.

If a hybrid method can be developed considering this method along with some existing methods, then false minutiae removal step may not be required in the post-processing step. The hybrid method should include morphological operation as a pre-processing step in addition to Gabor filtering for enhancement purpose of the fingerprint image. When it comes to the unclear images which are affected by noise, fingerprints that are not perfectly obtained during the initial sensing step or are obtained from a dry or cut finger, then the failure of the proposed method can be overcome using some hybrid approach. Thus this proposed method of feature extraction which stresses mainly on producing a clear image may serve helpful in the first two stages of fingerprint recognition system. The resulting minutiae can then be applied for further carrying on the fingerprint matching stage which is beyond the scope of this paper.

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