Effective Morphological Extraction of True Fingerprint Minutiae based on the Hit or Miss Transform

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ABSTRACT

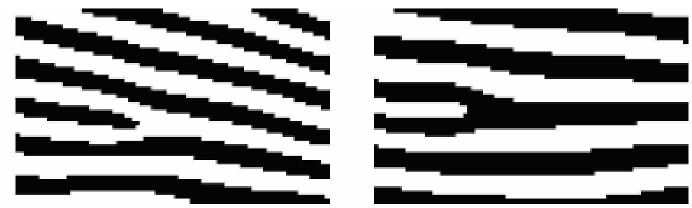
Fingerprints are the most widely used parameter for personal identification amongst all biometrics based personal authentication systems. As most Automatic Fingerprint Recognition Systems are based on local ridge features known as minutiae, marking minutiae accurately and rejecting false ones is critically important. In this paper we propose an algorithm for extracting minutiae from a fingerprint image using the binary Hit or Miss transform (HMT) of mathematical morphology. We have developed and tested structuring elements for different types of minutiae present in a fingerprint image to be used by the HMT after preprocessing the image with morphological operators. This results in efficient minutiae detection, thereby saving a lot of effort in the post processing stage. The algorithm is tested on a large number of images. Experimental results depict the effectiveness of the proposed technique.

Keywords : Biometrics, fingerprint image, minutiae extraction, Hit or Miss transform, mathematical morphology

1. INTRODUCTION

In today's advanced digital technology world, there is an increased requirement of security measures leading to the development of many biometrics based personal authentication systems. Biometrics is the science of uniquely recognizing humans based upon one or more intrinsic physical (e.g., fingerprint, iris, face, retina etc.) or behavioral (e.g., gait, signature etc.) traits. Fingerprints are the most widely used parameter for personal identification amongst all biometrics. The reason behind the popularity of fingerprint-based recognition among the biometrics-based security systems is the unchangeability of fingerprints during the human life span and their uniqueness [7]. However to meet the performance requirements of high security applications, multimodal biometrics [1, 5] is also used as it helps to minimize system error rates.

Fingerprint identification is commonly employed in forensic science to aid criminal investigations etc. A fingerprint is a unique pattern of ridges and valleys on the surface of finger of an individual. A ridge is defined as a single curved segment, and a valley is the region between two adjacent ridges. Most Automatic Fingerprint Recognition Systems are based on local ridge features known as minutiae. Sir Francis Galton (1822-1922) was the first person who observed the structures and permanence of minutiae. Therefore, minutiae are also called "Galton details".



(a) Ridge Ending (b) Ridge Bifurcation

Figure 1: Example of a ridge ending and a bifurcation.

They are used by forensic experts to match two fingerprints. There are about 150 different types of minutiae [2] categorized according to their configuration. Among these minutia types, "ridge ending" and "ridge bifurcation" are the most commonly used, since the other types of minutiae can be seen as combinations of "ridge endings" and "ridge bifurcations" (figure 2). Figure 1 illustrates the two most basic types of minutiae: ridge endings and bifurcations. It is these minutiae points which are used for determining uniqueness of a fingerprint.

Automated fingerprint recognition systems can be categorized as: verification or identification systems. The verification process either accepts or rejects the user's identity by matching against an existing fingerprint database. In identification, the identity of the user is established using fingerprints. Since accurate matching of fingerprints depends largely on ridge structures, the quality of the fingerprint image is of critical importance. However, in practice, a fingerprint image may not always be well defined due to elements of noise that corrupt the clarity of the ridge structures.

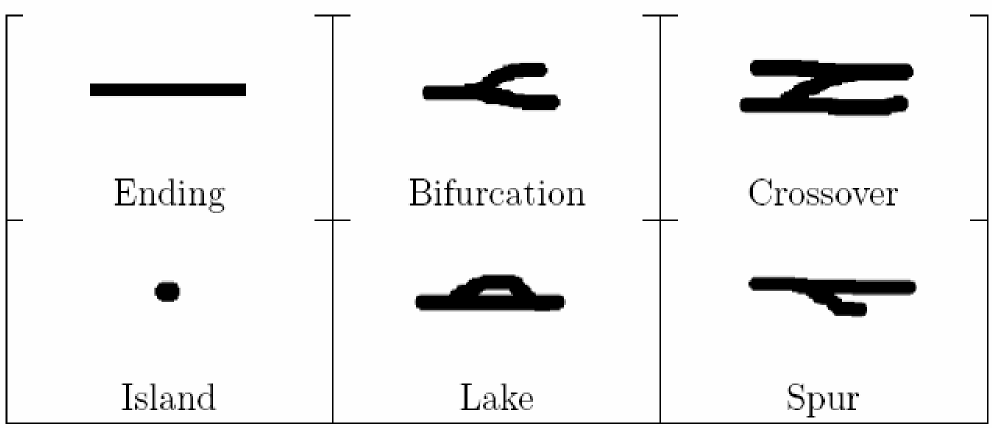


Figure 2 : Some common minutiae types.

This corruption may occur due to variations in skin and impression conditions such as scars, humidity, dirt, and non-uniform contact with the fingerprint capture device. Many algorithms [2, 16, 26, 27, 28] have been proposed in the literature for minutia analysis and fingerprint classification for better fingerprint verification and identification. Some algorithms classify the fingerprint pattern into different groups at the time of enrollment [30]. Their results also depend largely on the quality of the input image. Thus, image enhancement techniques are often employed to reduce the noise and to enhance the definition of ridges against valleys so that no spurious minutiae are identified. Several methods have been proposed for enhancement of fingerprint images which are based on image normalization and Gabor filtering (Hong's algorithm) [11], Directional Fourier filtering

[3], Binarization Method [23], Directional Filter Based Analysis [25], Fingerprint image thinning using PCNNs [9] etc. The Hong's algorithm inputs a fingerprint image and applies various steps for enhancement. Several other fuzzy techniques for image enhancement are also available [4, 20, 21, 32, 33].

Once the fingerprint image is enhanced minutiae points can be extracted. There are a lot of minutiae extraction algorithms available in the literature like direct gray scale ridge tracking strategy [7, 31] which work on gray scale images directly, minutiae extraction by run length encoding method [34] which does not require the fingerprint image to be thinned and other techniques based on extracting minutiae from skeletonised images using the crossing number algorithm [8, 10, 14, 15, 18, 19, 24]. The crossing number technique extracts ridge endings and bifurcations from a binarized skeletonised image by examining the local neighbourhood using a 3X3 window of each pixel and counting the number of 0 to 1 transitions in it. This method of extraction extracts a very large number of spurious minutiae together with true ones, thereby relying heavily on enormous post processing procedures including one by one minutia validation and invalidation[8, 14. 15].

In this paper we propose a novel algorithm for extracting minutiae from a fingerprint image using the binary Hit or Miss transform (HMT) of mathematical morphology. Morphological operators are basically shape operators and their composition allows the natural manipulation of shapes for the identification and the composition of objects and object features. We have developed and tested structuring elements for different types of minutiae present in a fingerprint image to be used by the HMT to extract valid minutiae, after preprocessing the image with such morphological operators. As mentioned earlier, the problem with other techniques is the generation of a large number of spurious minutiae together with true ones whereas our algorithm results in efficient minutiae detection, thereby saving a lot of effort in the post processing stage. The algorithm is tested on a large number of images. Experimental results depict the effectiveness of the proposed technique.

The rest of the paper is organized as follows: Section 2 introduces basic concepts and operations of mathematical morphology to be used in this paper. Section 3 describes the proposed algorithm. Experimental results are reported in Section 4. Section 5 concludes the paper.

2. MATHEMATICAL MORPHOLOGY

Mathematical morphology finds its place in computer vision as it emphasizes in shape information. It refers to a branch of nonlinear image processing and analysis that concentrates on the geometric structure within an image, it is mathematical in the sense that the analysis is based on set theory, topology, lattice, random functions, etc. Mathematical morphology is considered to be a powerful tool to extract information from images. We briefly discuss some mathematical morphology transformations [22] in this section.

2.1 Erosion and Dilation.

Erosion and dilation are considered the primary morphological operations. Erosion shrinks or thins object in a binary image where as Dilation grows or thickens objects. Erosion and Dilation constitute the basis for more complex morphological operators and can be defined as follows:
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

$$(A \Theta B) = \{ z \mid (B)_z \cap A^c \neq \emptyset \} \quad (1)$$

The dilation of A by B, is denoted by $(A \oplus B)$, and is expressed as

$$(A \oplus B) = \{ z \mid (\hat{B})z \cap A \neq \emptyset \} \quad (2)$$

In other words dilation of A by B is the set of all structuring element origin locations where the reflected and translated B overlaps at least some portion of A.

2.2 Opening and Closing.

Closing and opening are two examples of elementary combinations of erosion and dilation. Visually, opening smoothes contours, break narrow isthmuses and eliminates small islands. The gray-scale opening of A by B, denoted by $A \circ B$, is simply erosion of A by B, followed by dilation of the result by B as,

$$(A \circ B) = (A \ \Theta \ B) \oplus B \tag{3}$$

On the other hand, closing smoothes the contours, fills narrow gulfs and eliminate small holes. The gray-scale closing of A by B, denoted by $A \bullet B$ is a dilation followed by an erosion, as

$$(A \bullet B) = (A \oplus B) \ \Theta \ B \tag{4}$$

2.3 The Hit or Miss Transformation(HMT)

The morphological Hit or Miss Transform is the localization operator in mathematical morphology. It finds occurrences of an object and its nominal surroundings in a set or an image. It is a natural operation to select out pixels that have certain geometric properties, such as corner points, isolated points or border points and performs template matching.

The Hit or Miss Transformation of A by B is denoted by $A \otimes B$. Here B is a structuring element pair $B = (B_1, B_2)$, rather than a single element as before. The hit and miss transformation is defined in terms of these two structuring elements as

$$A \otimes B = (A \ \Theta \ B_1) \cap (A^c \ \Theta \ B_2) \tag{5}$$

Erosion with B_1 determines the location of foreground pixels and erosion of the complement with B_2 determines the location of the background pixels. Performing intersection of these two operations outputs an image which consists of all locations that match the pixels in B_1 (a hit) and that have none of the pixels in B_2 (a miss). In this paper HMT has been used as a building block for complex morphological operators like spur removal, bridge removal, thinning and minutiae detection.

3. PROPOSED TECHNIQUE

In this paper we propose a minutiae extraction algorithm which extracts minutiae using the morphological Hit or Miss Transform. But, as discussed earlier, the success of any minutiae extraction technique depends on the quality of the input image, the image needs to be enhanced before processing it for minutiae extraction. Given in figure 3 is the schematic diagram of the proposed technique. The details of the various steps are explained in the following subsections

3.1 Image Enhancement

The performance of any minutiae detection algorithm relies heavily on the quality of the input fingerprint image. For a fingerprint image of low quality, a large number of false minutiae are extracted during minutiae extraction. Hence, it is important to enhance the input fingerprint before performing minutiae extraction to cater to the following two aspects:

- Noise
- Broken ridges.

A lot of fingerprint enhancement methods based on input image quality have been proposed in the literature [4, 9, 11,12, 20, 23, 32]. We have used the Hong's algorithm [11] for the enhancement of our input fingerprint image, which is based on the convolution of the image with Gabor filters tuned to the local ridge orientation and frequency. Firstly, the image is segmented to extract it from the background. Next, it is normalized so that it has a prespecified mean and variance. After calculating the local orientation and ridge frequency around each pixel, the Gabor filter is applied to each pixel location in the image. As a result the filter enhances the ridges oriented in the direction of local orientation. Hence the filter increases the contrast between the foreground ridges and the background, while effectively reducing noise [figure 4].

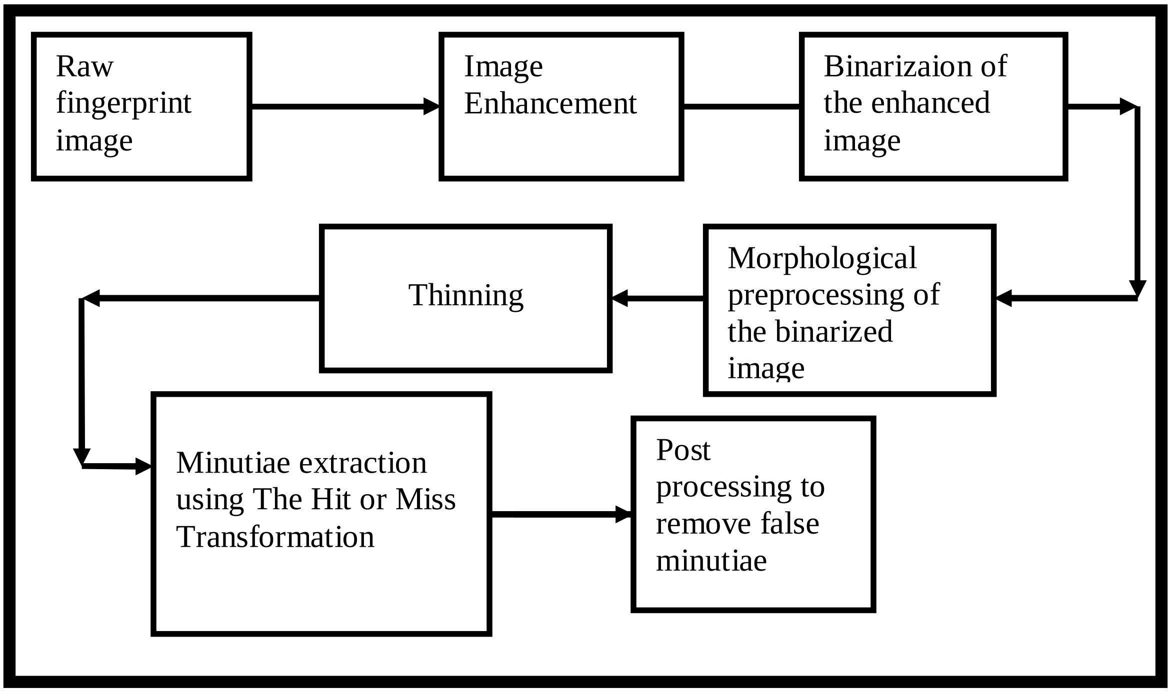


Figure 3 : Block diagram of the proposed Algorithm.

3.2 Binarization

Image binarization converts a 256 gray level image to a binary image (i.e. with only two levels – black and white[figure 4]. The simplest way to use image binarization is to choose a threshold value, and classify all pixels with values above this threshold as white, and all other pixels as black. The problem is how to select the correct threshold. In many cases, finding one threshold compatible to the entire image is very difficult, and in many cases even impossible. Therefore, adaptive image binarization is needed where an optimal threshold is chosen for each image area [6]. There are other methods also available for image binarization [17].

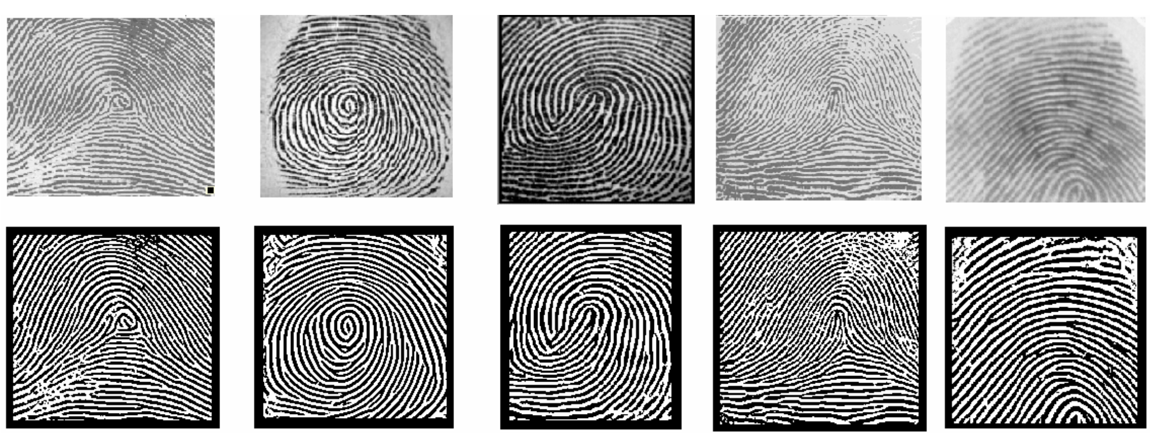


Figure 4 : The first row shows the original images. The second shows the enhanced and binarized images correspondingly.

3.3 Morphological Preprocessing

After close examination of the binarized image, it can be seen that the misconnections and isolated regions (dots, holes, islands etc.) in a binary image may introduce a number of spurious minutiae in thinned images. Therefore some morphological operators are applied to the binarized image as follows:

1. Spur removal

Spurs are short length irregularities in the boundary of the original object. They can be removed by a process called pruning. The spur operator is shown in figure 5.

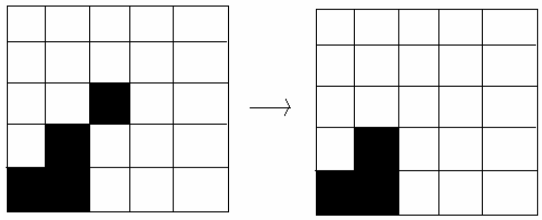
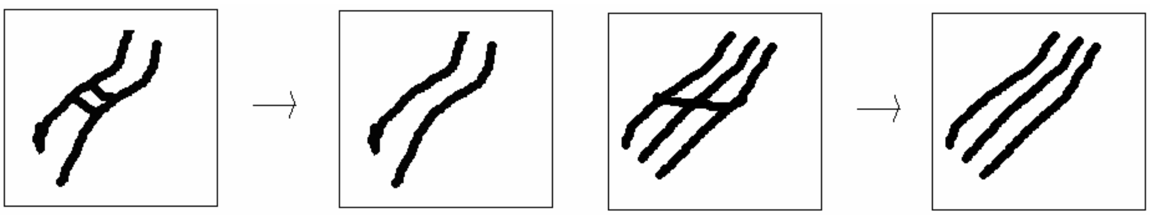


Figure 5: Spur operator.

2. Spurious bridge removal

Some linked parallel valleys may be separated to eliminate spurious bridges(figure 6) in the skeleton image.



(a) **(b)**

Figure 6(a) and (b) : Spurious bridges removal.

3. Spurious holes removal .

Spurious holes are regions (figure 7) with an area (number of pixels) below a threshold w1. The threshold value has to be selected appropriately so that it is not so small that it does not remove the spurious hole and not so large that it distorts the actual image. These regions are identified and filled so that the subsequent thinning operation does not produce spurious closed loops.

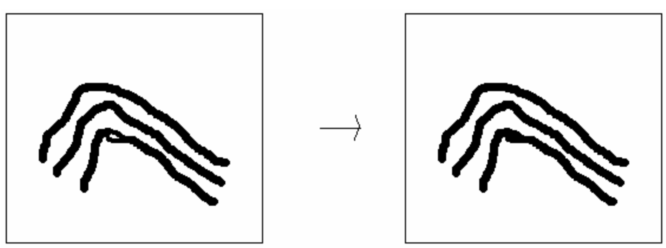


Figure 7 : Spurious holes removal.

4 Isolated islands removal

Islands (figure 8) are short lines with an area below a threshold w2. Removing these areas eliminates any spurious dots and islands from the binarized image.

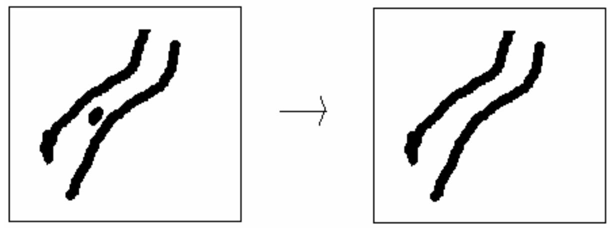


Figure 8 : Islands removal

3.4 Thinning

The next step is to thin the processed binary image using the morphological thinning operation. The thinning algorithm removes pixels from ridges until the ridges are one pixel wide[29]. In this paper, it is related to the hit or miss transform and can be expressed quite simply in terms of it . The thinning of an image **I** by a structuring element J = (J_1, J_2) is given by :

Thin (**I**, J) = **I** - (**I** $\otimes$ J) (6)

where, the subtraction is the logical subtraction defined by:

X – Y = X $\cap$ Not Y (7)

The operation is repeatedly applied until it causes no further changes to the image(i. e., until convergence). The structuring element sequence J used by us is shown in figure 9. Structuring elements from (i) to (viii) show the sequence for J_1 and from (ix) to (xvi) show the sequence for J_2(complement of J_1). The image is thinned using the structuring element pairs (J_1^i, J_2^i) , i = 1..8 in sequence. Doing so produces a connected skeleton of the image. The process is repeated in cyclic fashion until the operation produces any further change in the image (figure 10).

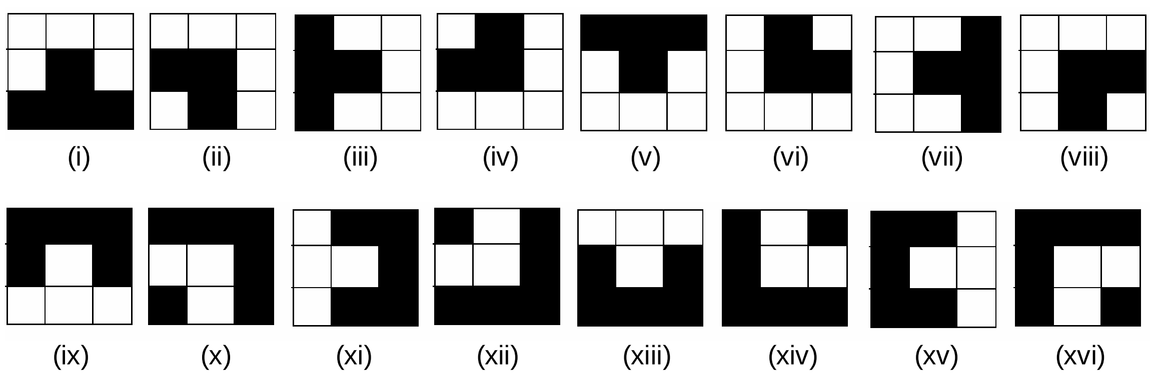


Figure 9 : (i) to (viii) The structuring element sequence $J_1 = (J_1^1 , J_1^2 , J_1^3 , J_1^4 , J_1^5 , J_1^6 , J_1^7 , J_1^8)$. (ix) to (xvi) The structuring element sequence $J_2 = (J_2^1 , J_2^2 , J_2^3 , J_2^4 , J_2^5 , J_2^6 , J_2^7 , J_2^8)$.

3.5 Minutiae Extraction Using HMT

In this step, we shall extract the two basic types of minutiae points (ridge terminations and ridge bifurcations) from the thinned image obtained from the previous step using the Hit or Miss Transformation. For this purpose, we have developed structuring elements to for different types of minutiae present in the fingerprint image, to be utilized by the HMT. Although this computes all the minutiae points, some false minutiae may occur due to some superfluous information in the thinned image. They are removed in the last step of the algorithm. However, it can be seen from the final results that the number of false minutiae is lesser as compared to other techniques as the image is already preprocessed with morphological operators before thinning.

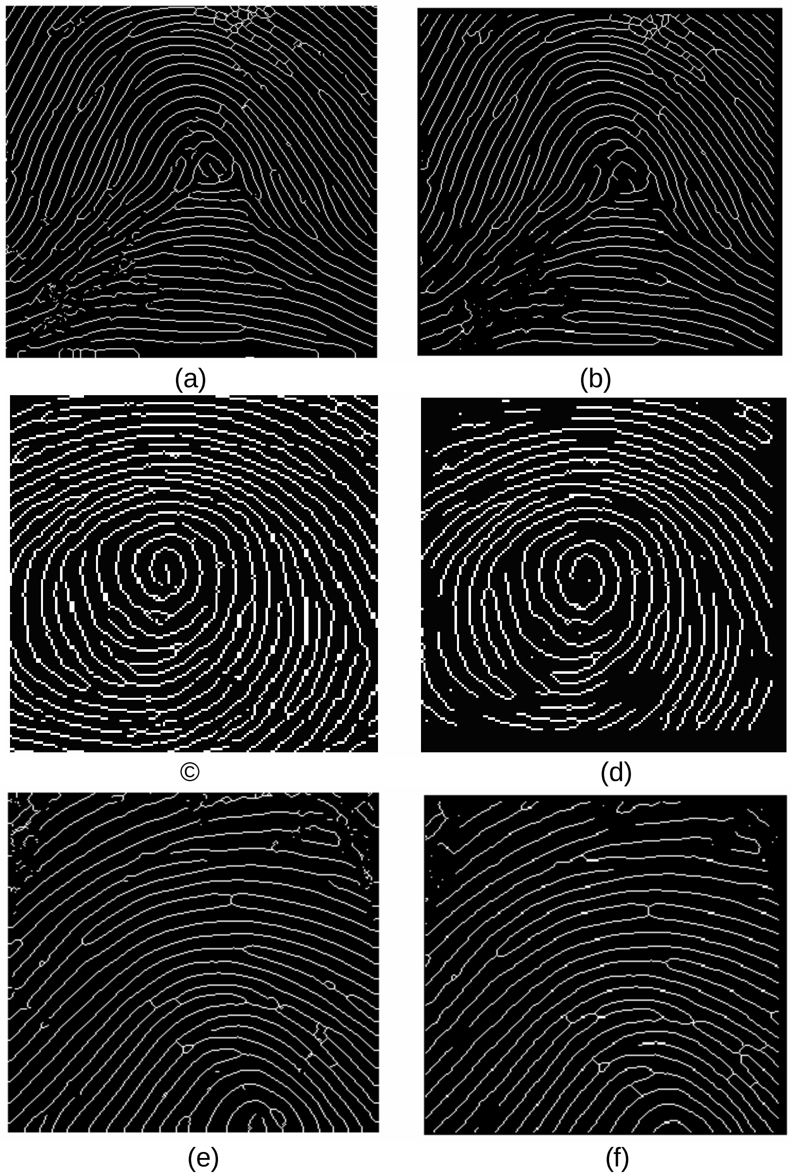


Figure 10 : (a), (c) and (e) show the thinned image after applying the thinning operator directly to the binarized images. (b) ,(d) and (f) show the thinned image after applying the thinning operator to the corresponding morphologically processed binarized images.

3.5.1 Extracting Ridge Terminations

Ridge endings are those pixels in an image which have only one neighbour in a 3X3 neighbouhood. The minutiae image M1 containing ridge terminations is given by applying Hit or Miss transform on I by J as follows:

$$M1 = I \otimes J \tag{8}$$

where, I is the thinned image and J is the sequence of structuring element pairs (J_1, J_2) .

Applying eq. 5,

$$I \otimes J = (I \ominus J_1) \cap (I^c \ominus J_2) \tag{9}$$

The structuring element sequence J that we have designed for determining endpoints in an image in this paper is shown in figure 11.The structuring elements have been designed in such a way so as to select all pixels from image I that have a single neighbour in a 3X3 neighbourhood and leave all pixels that have more than one neighbour. Each of the structuring element pairs (J_1^i, J_2^i) , i = 1..8, is applied in sequence and the collective output gives the ridge endpoints in the fingerprint image.

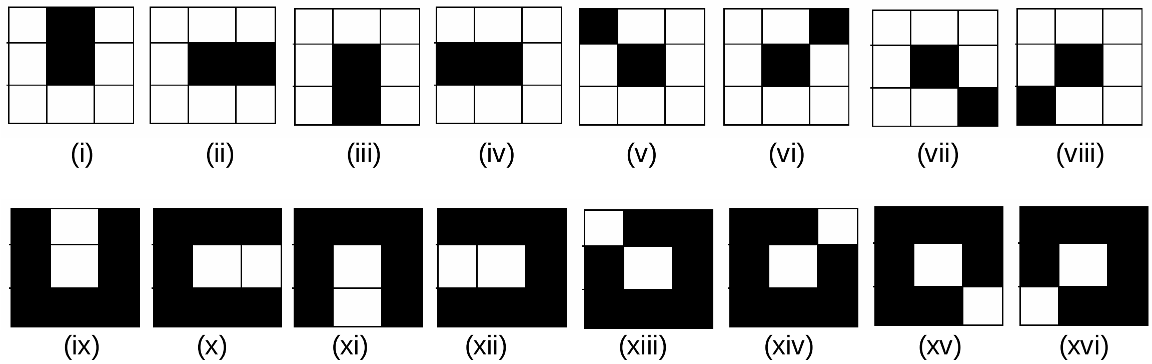


Figure 11 : (i) to (viii) The structuring element sequence $J_1 = (J_1^1, J_1^2, J_1^3, J_1^4, J_1^5, J_1^6, J_1^7, J_1^8)$. (ix) to (xvi) The structuring element sequence $J_2 = (J_2^1, J_2^2, J_2^3, J_2^4, J_2^5, J_2^6, J_2^7, J_2^8)$.

3.5.2 Extracting Ridge Bifurcations

Ridge bifurcations are those pixels in an image which have only three neighbours in a 3X3 neighbourhood and these neighbours are not adjacent to each other. The minutiae image M2 containing ridge terminations is given by:

$$M2 = I \otimes J \tag{10}$$

where, I is the thinned image and J is the sequence of structuring element pairs (J_1, J_2). Applying eq. 5,

$$I \otimes J = (I \ \Theta \ J_1) \cap (I^c \ \Theta \ J_2) \tag{11}$$

The structuring element sequence J that we have designed for determining endpoints in an image in this paper is shown in figure 12. Structuring elements from (i) to (viii) show the sequence for J_1 and from (ix) to (xvi) show the sequence for J_2(complement of J_1). The structuring elements are designed as per an actual bifurcation point in a fingerprint image, where each pixel has exactly three neighbours which are not next to each other. Each of the structuring element pairs (J_1^i, J_2^i) , i = 1..8, is applied in sequence and the collective output gives the ridge bifurcations in the fingerprint image.

When the Hit or Miss structuring elements are small, a faster way to compute the HMT is to use a lookup table [21].

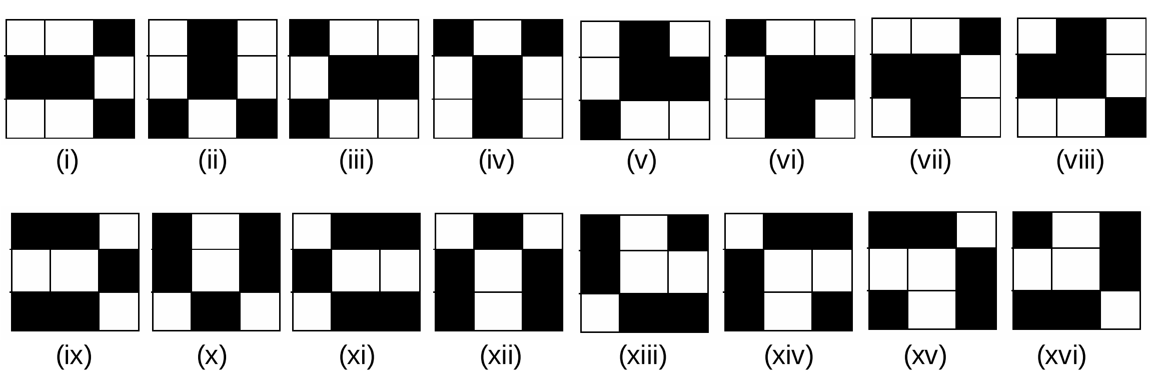


Figure 12 : (i) to (viii) The structuring element sequence $J_1 = (J_1^1, J_1^2, J_1^3, J_1^4, J_1^5, J_1^6, J_1^7, J_1^8)$. (ix) to (xvi) The structuring element sequence $J_2 = (J_2^1, J_2^2, J_2^3, J_2^4, J_2^5, J_2^6, J_2^7, J_2^8)$.

3.6 Post Processing.

The minutiae set extracted in the previous step contains many false or spurious minutiae. The following simple post processing steps remove them.

1. If the distance between two bifurcations is less than a threshold T and they are in the same ridge, remove both of them (merge, bridge, ladder, lake in figure13).
2. If the distance between two terminations is less than a threshold T and the difference between their angles of orientation is very small, then the two minutiae are regarded as false (break, multiple breaks in figure 13) and are removed.

If the distance between a bifurcation and a termination is less than a threshold T such that T is the average inter ridge width , then they are removed(spur, break and merge in the figure).

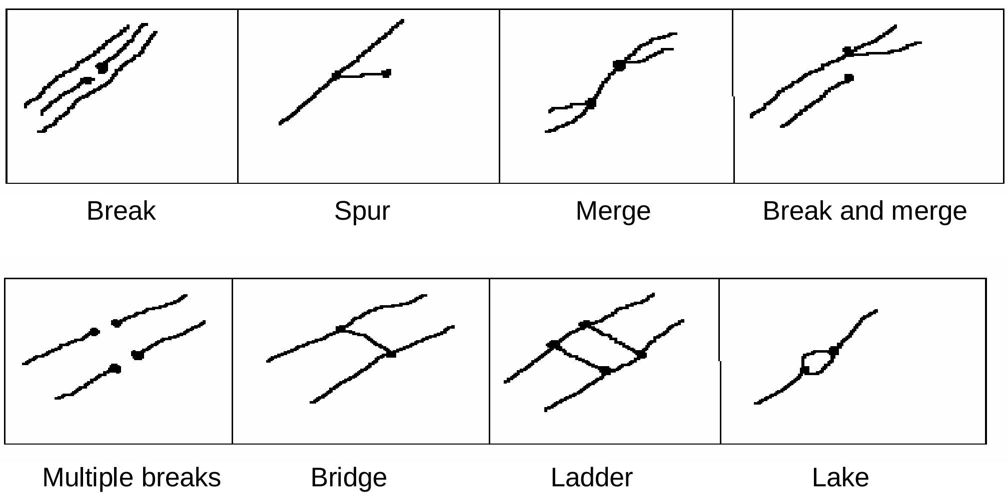


Figure 13: Some common false minutiae points (black dots).

4. EXPERIMENTAL RESULTS

In our experimental work, we have tested the above algorithm on FVC(2002) fingerprint database. The database contains 40 different fingers and eight impressions of each finger, which makes it a total of 40X8=320 fingerprints. Minutiae are extracted at four stages from the images as follows and the results are tabulated.

1). Original raw images.
2). Enhanced and then thinned (repairing broken ridges etc.).
3). Preprocessed thinned images (Removal of spurs, spurious bridges, filling holes etc.).
4). Post processing the minutiae to get rid of the spurious ones.

We have tested the proposed algorithm using two quantity measures namely Sensitivity and Specificity which indicate the ability of the algorithm to detect the genuine minutiae and remove the false minutiae for fingerprint image [13]. The performance of the proposed algorithm has been measured based on the missing and the spurious minutiae after each stage (figure 14).

$$\text{Sensitivity} = 1 - \frac{\text{Missed Minutiae}}{\text{Ground Truth Minutiae}} \quad (12)$$

$$\text{Specificity} = 1 - \frac{\text{False Minutiae}}{\text{Ground Truth Minutiae}} \quad (13)$$

Table 1 shows the total number of minutiae together with the number of ridge endings and bifurcations separately at each stage. It also shows the reduction in ridge endings and bifurcations after each stage. It also shows the ground truth minutiae in each case. The found truth minutiae have been calculated by manually inspecting the fingerprint image.

Image	Ground Truth Minutiae	Stage	Total minutiae	Ridge endings	Ridge bifurcations	Total Red. (%)	End. Red. (%)	Bif. Red. (%)
I1	59(36+23)	Original	347	201	146	-	-	-
		Enhanced	315	180	135	9.2	10.4	7.5
		Preprocessed	215	101	114	31.7	43.9	15.6
		Post processed	62	38	24	71.1	62.4	78.9
I2	23(12+11)	Original	114	75	39	-	-	-
		Enhanced	88	56	29	22.8	25.3	25.6
		Preprocessed thinned	61	42	19	30.7	25.0	34.5
		Post processed	23	11	12	62.2	73.8	36.8
I3	23(9+14)	Original	201	106	95	-	-	-
		Enhanced	73	30	43	63.7	71.7	54.7
		Preprocessed thinned	54	20	34	26.0	33.3	20.9
		Post processed	22	8	14	57.4	60.0	58.8
I4	32(13+19)	Original	360	110	250	-	-	-
		Enhanced	121	52	89	66.3	52.7	64.4
		Preprocessed thinned	76	24	52	37.2	53.9	41.6
		Post processed	33	14	17	56.6	41.7	67.3

Table 1 : Total, endings and bifurcations with % reduction in false minutiae after each stage.

Table 2 lists the total, missed and false number of minutiae before and after the post processing stage together with the sensitivity and specificity values. The high values of sensitivity and specificity in the end, suggest the effectiveness of the proposed technique. Since our technique works on thinned binarized images, the most widely used technique applicable to such images in the literature is the crossing number technique. Hence, we have compared both of them and table 3 shows the comparative results of our technique with the much used crossing number technique. It can be clearly seen that the results of the proposed algorithm are better at both before and after post processing stages. This is so because most crossing number techniques rely on complicated and extensive post processing algorithms to improve their result.

Image	Before Post processing			After Post processing			Final Sensitivity %	Final Specificity %
	Total	Missed	False	Total	Missed	False		
I1	215	1	157	62	1	4	98.3	93.2
I2	61	1	40	23	1	1	95.7	95.7
I3	64	1	43	22	1	0	95.7	100
I4	76	2	45	31	2	1	93.6	96.9

Table 2 : Total, missed and false number of minutiae before and after the post processing stage together with the sensitivity and specificity in the proposed technique.

Stage	Image	Proposed Technique			Crossing Number Technique		
		Total	Endings	Bifurcations	Total	Endings	Bifurcations
Before Post processing	I1	215	101	114	589	303	286
	I2	61	42	19	189	109	80
	I3	54	20	34	183	69	114
	I4	76	24	52	189	85	104
After Post processing	I1	62	38	24	145	67	78
	I2	23	11	12	38	24	14
	I3	22	8	14	78	26	52
	I4	33	14	17	41	15	26

Table 3 : Total minutiae together with endings and bifurcations before and after the post processing stage in the proposed as well as the crossing number technique.

5. CONCLUSIONS

The proposed technique depicts the successful usage of the Hit or Miss Transform on thinned fingerprint images for efficient minutiae extraction. It clearly shows that preprocessing a fingerprint image with morphological operators before thinning removes superfluous information and extracts a clear and reliable ridge map structure from the input fingerprint image thereby giving better results in minutiae extraction. This also reduces a lot of effort in the post processing stage as the number of spurious minutiae is comparatively lesser. The high values of Sensitivity and Specificity in the end and the comparative results with the crossing number technique illustrate the encouraging performance of our method. Our future work would be to consider fuzzy morphology for minutiae detection.

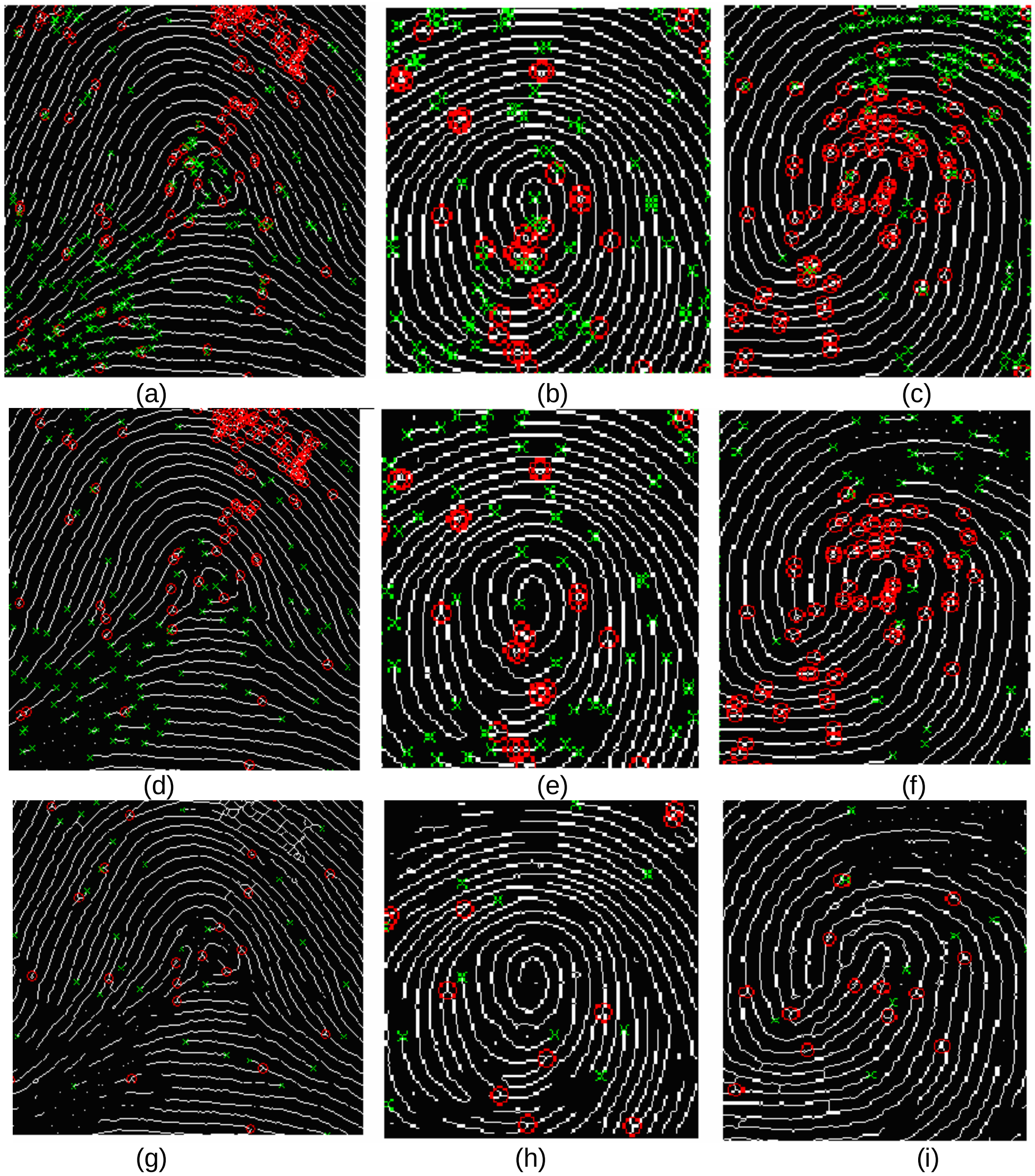


Figure 14(a), (b), (c) show minutiae on enhanced images I1, I2 and I3 respectively, which have been thinned but not morphologically preprocessed. (d), (e), (f) show minutiae on enhanced and thinned images I1, I2 and I3 respectively, which have been morphologically preprocessed. (g), (h) and (i) show the finally post processed minutiae on images I1, I2 and I3 respectively. In all the images endings are shown as x and bifurcations are shown as o.

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