A STUDY ON FINGERPRINT IMAGE ENHANCEMENT AND MINUTIAE EXTRACTION TECHNIQUES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
in
Computer Science

By

PRAVEEN NAMBURU

Department of Computer Science and Engineering
National Institute of Technology
Rourkela
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Under the Guidance of

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CERTIFICATE

This is to certify that the thesis entitled, **“A study on Fingerprint Image Enhancement and Minutiae Extraction Techniques”** submitted by Sri **Praveen Namburu** in partial fulfillment of the requirements for the award of Master of Technology Degree in Computer Science and Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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May 2007

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Abstract

Existing security measures rely on knowledge-based approaches like passwords or token based approaches such as swipe cards and passports to control access to physical and virtual spaces. Though ubiquitous, such methods are not very secure. Tokens such as badges and access cards may be shared or stolen. Furthermore, they cannot differentiate between authorized user and a person having access to the tokens or passwords.

Biometrics such as fingerprint, face and voice print offers means of reliable personal authentication that can address these problems and is gaining citizen and government acceptance. Fingerprints were one of the first forms of biometric authentication to be used for law enforcement and civilian applications.

Reliable extraction of features from poor quality prints is the most challenging problem faced in the area of fingerprint recognition. In this thesis, we introduce a new approach for fingerprint image enhancement based on the Gabor filter have been widely used to facilitate various fingerprint applications such as fingerprint matching and fingerprint classification. Gabor filters are band pass filters that have both frequency-selective and orientation-selective properties, which means the filters can be effectively tuned to specific frequency and orientation values. The proposed analysis and enhancement algorithm simultaneously estimates several intrinsic properties of the fingerprint such as the foreground region mask, local ridge orientation and local frequency. We also objectively measure the effectiveness of the enhancement algorithm and show that it can improve the sensitivity and recognition accuracy of existing feature extraction and matching algorithms.

We also present a new feature extraction algorithm is the Crossing Number (CN) concept. This method involves the use of the skeleton image where the ridge flow pattern is eight-connected. The minutiae are extracted by scanning the local neighborhood of each ridge pixel in the image using a 3x3 window. The CN value is then computed, which is defined as half the sum of the differences between pairs of adjacent pixels in the eight-neighborhood. The algorithm has several advantages over the techniques proposed in literature such as increased computational efficiency, improved localization and higher sensitivity.

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Chapter 1

INTRODUCTION

Motivation
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INTRODUCTION

In an increasingly digital world, reliable personal authentication has become an important human computer interface activity. National security, e-commerce, and access to computer networks are some examples where establishing a person’s identity is vital. Existing security measures rely on knowledge-based approaches like passwords or token-based approaches such as swipe cards and passports to control access to physical and virtual spaces. Though ubiquitous, such methods are not very secure. Tokens such as badges and access cards may be shared or stolen. Passwords and PIN numbers may be stolen electronically. Furthermore, they cannot differentiate between authorized user and a person having access to the tokens or knowledge.

Biometrics such as fingerprint, face and voice print offers means of reliable personal authentication that can address these problems and is gaining citizen and government acceptance.

1.1 Biometrics

Biometrics is the science of verifying the identity of an individual through physiological measurements or behavioral traits. Since biometric identifiers are associated permanently with the user they are more reliable than token or knowledge based authentication methods. Biometrics offers several advantages over traditional security measures. These include

1. **Non-repudiation**: With token and password based approaches, the perpetrator can always deny committing the crime pleading that his/her password or ID was stolen or compromised even when confronted with an electronic audit trail. There is no way in which his claim can be verified effectively. This is known as the problem of deniability or of ’repudiation’. However, biometrics is indefinitely associated with a user and hence it cannot be lent or stolen making such repudiation infeasible.

2. **Accuracy and Security**: Password based systems are prone to dictionary and brute force attacks. Furthermore, such systems are as vulnerable as their weakest password. On the other hand, biometric authentication requires the physical presence of the user and therefore cannot be circumvented through a dictionary or brute force style attack. Biometrics has also been

shown to possess a higher bit strength compared to password based systems [42] and is therefore inherently secure.

3. **Screening**: In screening applications, we are interested in preventing the users from assuming multiple identities (e.g. a terrorist using multiple passports to enter a foreign country). This requires that we ensure a person has not already enrolled under another assumed identity before adding his new record into the database. Such screening is not possible using traditional authentication mechanisms and biometrics provides the only available solution.

The various biometric modalities can be broadly categorized as

- **Physical biometrics**: This involves some form of physical measurement and includes modalities such as face, fingerprints, iris-scans, hand geometry etc.

- **Behavioral biometrics**: These are usually temporal in nature and involve measuring the *way* in which a user performs certain tasks. This includes modalities such as speech, signature, gait, keystroke dynamics etc.

- **Chemical biometrics**: This is still a nascent field and involves measuring chemical cues such as odor and the chemical composition of human perspiration.

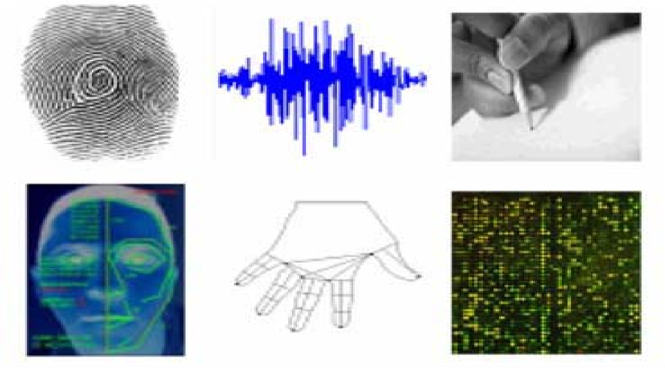


Figure 1.1: Various biometric modalities: Fingerprints, speech, handwriting, face, hand geometry and chemical biometrics

It is also instructive to compare the relative merits and de-merits of biometric and password/cryptographic key based systems. Table 1.1 provides a summary of them.

Depending on the application, biometrics can be used for identification or for verification. In verification, the biometric is used to validate the claim made by the individual. The biometric of the user is compared with the biometric of the claimed individual in the database. The claim is rejected or accepted based on the match. (In essence, the system tries to answer the question, ”Am I whom I claim to be?”). In identification, the system recognizes an individual by comparing his biometrics with every record in the database. (In essence, the system tries to answer the question,

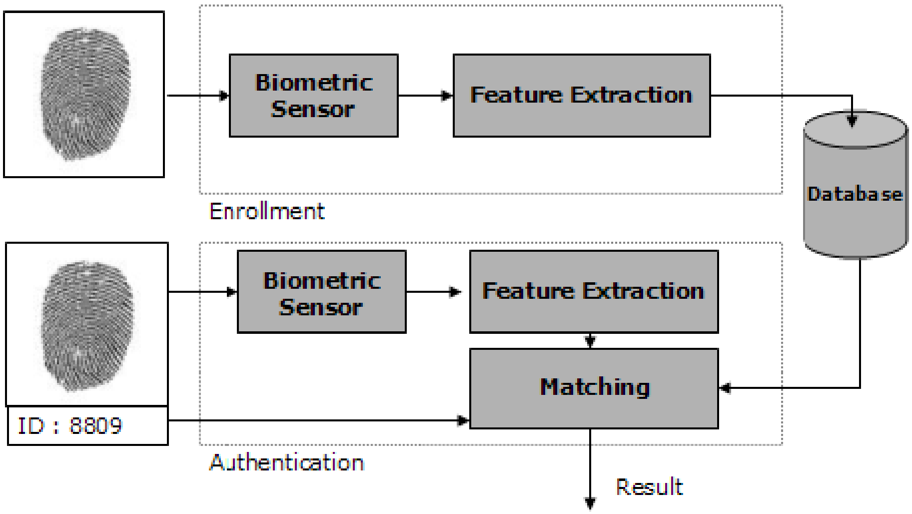


Figure 1.2: General architecture of a biometric system

”Who am I?”). In this thesis, we will be dealing mainly with the problem of verification using fingerprints. In general, biometric verification consists of two stages (Figure 1.2) (i) Enrollment and (ii) Authentication. During enrollment, the biometrics of the user is captured and the extracted features (template) are stored in the database. During authentication, the biometrics of the user is captured again and the extracted features are compared with the ones already existing in the database to determine a match. The specific record to fetch from the database is determined using the claimed identity of the user. The database itself may be central or distributed with each user carrying his template on a smart card.

1.1.1 The Verification Problem

Here we consider the problem of biometric verification in a more formal manner. In a verification problem, the biometric signal from the user is compared against a single enrolled template. This template is chosen based on the claimed identity of the user. Each user i is represented by a biometric Bi. It is assumed that there is a one-to-one correspondence between the biometric Bi and the identity i of the individual. The feature extraction phase results in a machine representation (template) Ti of the biometric.

During verification, the user claims an identity *j* and provides a biometric signal *Bj*. The feature extractor now derives the corresponding machine representation *Tj.* The recognition consists of computing a similarity score $S\ (Ti,\ Tj)$. The claimed identity is assumed to be true if the $S(Ti,\ Tj) > Th$ for some threshold *Th* The choice of the threshold also determines the trade-off between user convenience and system security as will be seen in the ensuing section.

1.1.2 Performance Evaluation

Unlike passwords and cryptographic keys, biometric templates have high uncertainty. There is considerable variation between biometric samples of the same user taken at different instances of time. Therefore the match is always done probabilistically. This is in contrast to exact match required by password and token based approaches. The inexact matching leads to two forms of errors

- **False Accept** An impostor may sometime be accepted as a genuine user, if the similarity with his template falls within the intra-user variation of the genuine user.

- **False Reject** When the acquired biometric signal is of poor quality, even a genuine user may be rejected during authentication. This form of error is labeled as a ’false reject’.

The system may also have other less frequent forms of errors such as

- **Failure to enroll (FTE)** It is estimated that nearly 4% of the population have illegible fingerprints. This consists of senior population, laborers who use their hands a lot and injured individuals. Due to the poor ridge structure present in such individuals, such users cannot be enrolled into the database and therefore cannot be subsequently authenticated. Such individuals are termed as ’goats’. A biometric system should have exception handling mechanism in place to deal with such scenarios.
- **Failure to authenticate (FTA)** This error occurs when the system is unable to extract features during verification even though the biometric was legible during enrollment. In case of fingerprints this may be caused due to excessive sweating, recent injury etc. In case of speech, this may be caused to due cold, sore throat etc. It should be noted that this error is distinct from False Reject where the rejection occurs during the matching phase. In FTA, the rejection occurs in the feature extraction stage itself.

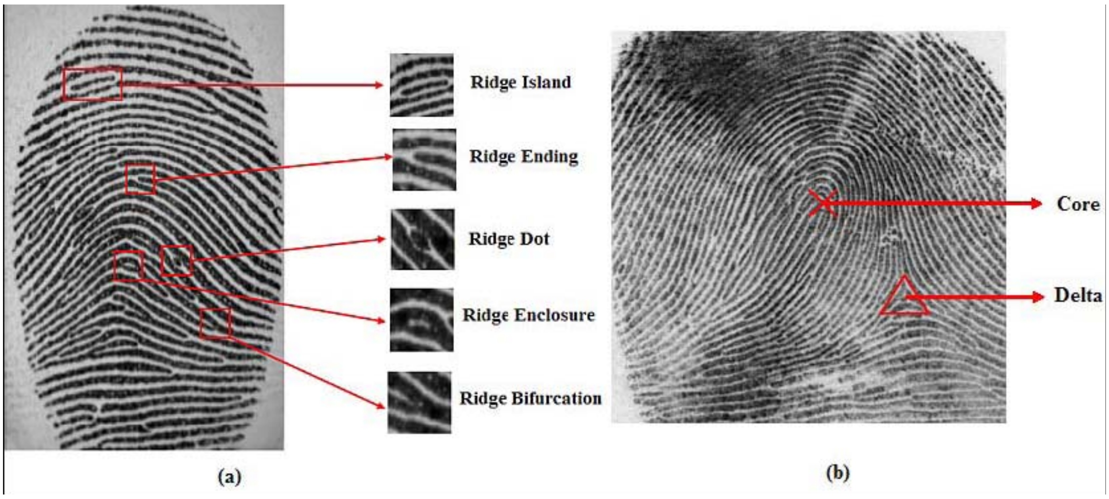


Figure 1.3: (a) Local Features: Minutiae (b) Global Features: Core and Delta

The fingerprint surface is made up of a system of ridges and valleys that serve as friction surface when we are gripping the objects. The surface exhibits very rich structural information when examined as an image. The fingerprint images can be represented by both global as well as local features. The global features include the ridge orientation, ridge spacing and singular points such as core and delta. The singular points are very useful from the classification perspective (See Figure 1.4). However, verification usually relies exclusively on minutiae features. Minutiae are local features marked by ridge discontinuities. There are about 18 distinct types of minutiae features that include ridge endings, bifurcations, crossovers and islands. Among these, *ridge endings* and *bifurcation* are the commonly used features.(See Figure 1.3). A ridge ending occurs when the ridge flow abruptly terminates and a ridge bifurcation is marked by a fork in the ridge flow. Most matching algorithms do not even differentiate between these two types since they can easily get exchanged under different pressures during acquisition. Global features do not have sufficient discriminative power on their own and are therefore used for binning or classification before the extraction of the local minutiae features.

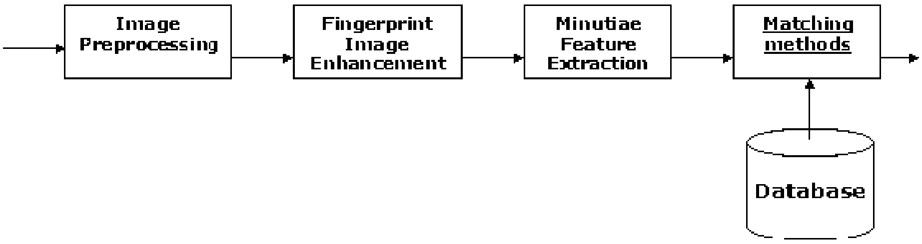


Figure 1.4: General architecture of a fingerprint verification system

regular images, the fingerprint image represent a system of oriented texture and has very rich structural information within the image. Furthermore, the definition of noise and unwanted artifacts are also specific to fingerprints. The fingerprint image enhancement algorithms are specifically designed to exploit the periodic and directional nature of the ridges. Finally, the minutiae features are extracted from the image and are subsequently used for matching. Although research in fingerprint verification research has been pursued for several decades now, there are several open research challenges still remaining, some of which will be addressed in the ensuing sections of this thesis.

1.1. MOTIVATION:

The motivation behind this fingerprint image enhancement and Minutiae extraction process is to improve the quality of fingerprint and to extract the minutiae points. And in the extraction process we should not get the false minutiae and preserve the true ridge endings and ridge bifurcations.

The minutia extracted from the fingerprint heavily depends upon the quality of the input finger print. In order to extract true Minutiae from the fingerprint we need to remove to noise from the input image and for that we need an enhancement algorithm.

1.2 THESIS ORGANIZATION:

This report contains 5 chapters. Chapter 2 gives the overview of the fingerprint enhancement and minutiae Extraction techniques. Chapter 3 gives the existing algorithms for the fingerprint enhancement and minutiae extraction. Chapter 4 gives the proposed algorithm for fingerprint enhancement and minutiae extraction. Chapter 5 will gives the conclusion and the future work.

Chapter 2

LITERATURE REVIEW

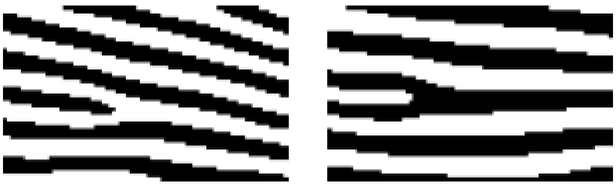
Fingerprint Image Enhancement
Binarization method
Enhancement using Gabor filter
Enhancement in wavelet domain

LITERATURE REVIEW

Fingerprints have been used for over a century and are the most widely used form of biometric identification. Fingerprint identification is commonly employed in forensic science to support criminal investigations, and in biometric systems such as civilian and commercial identification devices. Despite this widespread use of fingerprints, there has been little statistical work done on the uniqueness of fingerprint minutiae. In particular, the issue of how many minutiae points should be used for matching a fingerprint is unresolved.

The fingerprint of an individual is unique and remains unchanged over a lifetime. A fingerprint is formed from an impression of the pattern of ridges on a finger. A ridge is defined as a single curved segment, and a valley is the region between two adjacent ridges. The minutiae, which are the local discontinuities in the ridge flow pattern, provide the features that are used for identification. Details such as the type, orientation, and location of minutiae are taken into account when performing minutiae extraction.

Galton defined a set of features for fingerprint identification, which since then, has been refined to include additional types of fingerprint features. However, most of these features are not commonly used in fingerprint identification systems. Instead the set of minutiae types are restricted into only two types, ridge endings and bifurcations, as other types of minutiae can be expressed in terms of these two feature types. Ridge endings are the points where the ridge curve terminates, and bifurcations are where a ridge splits from a single path to two paths at a Y-junction. Figure 2.1 illustrates an example of a ridge ending and a bifurcation. In this example, the black pixels correspond to the ridges, and the white pixels correspond to the valleys.



(a) Ridge ending (b) Bifurcation

Figure 2.1: Example of a ridge ending and a bifurcation.

2.1 FINGERPRINT ENHANCEMENT:

A critical step in Automatic Fingerprint matching system is to automatically and reliably extract minutiae from input finger print images. How ever the performance of the Minutiae extraction algorithm relies heavily on the quality of the input fingerprint image. In order to ensure to extract the true minutiae points it is essential to incorporate the enhancement algorithm.

There are two ways in which we can enhance the input fingerprint image.

1. Binarization method. 2. Direct gray-level enhancement.

2.1.1 Binarization Method:

The ridge structures in fingerprint image are not always well defined, and therefore, an enhancement algorithm is needed to improve the clarity of the ridge and valley structure. The first method of enhancement algorithm is Binarization-based fingerprint image enhancement. This process is carried out using Local Histogram Equalization, Weiner filtering, and image Binarization. We use local Histogram equalization for contrast expansion and wiener filtering for noise reduction. The binarization process is applied by adaptive thresholding based on the local intensity mean. Finally Morphological filtering is applied to eliminate artifacts in the noise regions and to fill some gaps in valid ridgelines.

In some Binarization-based approaches the Binarization and thing process are preceded by a smoothing operation, based on convolution with a Gaussian mask, in order to regularize the starting image. The main stages in this algorithm include the fallowing:

1. Local Histogram Equalization
2. Wiener Filtering
3. Binarization and thinning
4. Morphological and Filtering.

1. Histogram equalization defines a mapping of gray-levels p into gray levels q such that the distribution of gray level q is uniform. This mapping stretches contrast (expands the range of gray levels) for gray levels near the histogram maxima. Histogram equalization locally by using a local window of 11X 11 pixels. This results in expanding the contrast locally, and changing the intensity of each pixel according to its local neighborhood.

2. Wiener method for noise reduction. In this pixels-wise adaptive Wiener Filtering is carried out. The filter is based on local statistics estimated from a local neighborhood η of size 3X3 of each pixel.
3. The operation that converts a grayscale image into a binary image is known as Binarization. Binarization process is carried out using an adaptive thresholding. Each pixel is assigned a new value (0 or 1) according to the intensity mean in local neighborhood. Thinned (one pixel thickness) ridge lines are obtained using morphological thinning operation.
4. In the thinned binary image there appears noise like: False fridge line and gaps within a true ridge lines. The false ridgeline connections are almost perpendicular to local ridge direction. Therefore, lines with similar features are automatically removed by the post-processing and binary filtering.

Drawbacks of the Binarization Method:

The main drawback of this method is that, after performing filtering, we will get some unwanted ridges and valleys. So there is a possibility of getting False Minutiae, and at the same time we lose some true ridge and valleys. So we lose True minutiae points.

To over come this drawback we will use Direct gray level-enhancement for fingerprint.

2.1.2 Direct Gray-level Enhancement:

In a gray-level fingerprint image, ridges and valleys in a local neighborhood form a sinusoidal-shaped plane wave which has well defined orientation and frequency. In order to enhance the gray-level fingerprint image we need to estimate these local orientations and frequencies. For the filtering purpose we will Gabor Filter is used which will use these orientation and frequency properties for enhancing the image.

Algorithm:

The main steps in this direct gray-level image enhancement are as fallows:

1. Normalization: The input finger print is normalized to have predefined mean and variance.
2. Local Orientation Estimation: The orientation image is estimated from the normalized image.

3. Local Frequency Image: The frequency image is estimated from the normalized image and the orientation image.
4. Filtering: A bank of Gabor filters which is tuned to the local ridge orientation and ridge frequency is applied to the ridge and valley pixels including the normalized image to obtain the enhanced image.

2.2 MINUTIAE EXTRACTION:

The basic algorithm performed minutiae extraction using the skeleton image. The approach involves using a 3 *x*3 window to examine the local neighborhood of each ridge pixel in the image. A pixel is then classified as a ridge ending if it has only one neighboring ridge pixel in the window, and classified as a bifurcation if it has three neighboring ridge pixels.

2.3 FINGERPRINT IMAGE ENHANCEMENT IN WAVELET DOMAIN:

Proposed Algorithm:

The main steps in the proposed algorithm include:

1. Segmentation 2. Normalization: 3.Wavelet Decomposition 4. Orientation Estimation 5. Frequency Estimation 6. Gabor Filtering 7. Wavelet Reconstruction 8. Binarization and thinning.

2.4 MINUTIAE EXTRACTION USING CN CONCEPT:

The most commonly employed method of minutiae extraction is the Crossing-Number (CN) concept. This method involves the use of the skeleton image where the ridge flow pattern is eight-connected. The minutiae are extracted by scanning the local neighborhood of each ridge pixel in the image using a 3x3 window. The CN value is then computed, which is defined as half the sum of the differences between pairs of adjacent pixels in the eight-neighborhood.

Chapter 3

FINGERPRINT ENHANCEMENT AND MINUTIAE EXTRACTION

Enhancement using Gabor filter
Methodology
Basic minutiae extraction

FINGERPRINT ENHANCEMENT USING GABOR FILTER

3.1 ENHANCEMENT USING GABOR FILTER

One of the most widely cited fingerprint enhancement techniques is the method employed by Hong et al., which is based on the convolution of the image with Gabor filters tuned to the local ridge orientation and ridge frequency. The main stages of this algorithm include normalization, ridge orientation estimation, ridge frequency estimation and filtering.

The first step in this approach involves the normalization of the fingerprint image so that it has a pre-specified mean and variance. Due to imperfections in the fingerprint image capture process such as non-uniform ink intensity or non-uniform contact with the fingerprint capture device, a fingerprint image may exhibit distorted levels of variation in grey-level values along the ridges and valleys. Thus, normalization is used to reduce the effect of these variations, which facilitates the subsequent image enhancement steps.

An orientation image is then calculated, which is a matrix of direction vectors representing the ridge orientation at each location in the image. The widely employed gradient-based approach is used to calculate the gradient, which makes use of the fact that the orientation vector is orthogonal to the gradient.

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

Fingerprint enhancement methods based on the Gabor filter have been widely used to facilitate various fingerprint applications such as fingerprint matching and fingerprint classification. Gabor filters are band pass filters that have both frequency-selective and orientation-selective properties, which means the filters can be effectively tuned to specific frequency and orientation values. One useful characteristic of fingerprints is that they are known to have well defined local ridge orientation and ridge frequency. Therefore, the enhancement algorithm takes advantage of this regularity of spatial structure by applying

Gabor filters that are tuned to match the local ridge orientation and frequency. Based on the local orientation and ridge frequency around each pixel, the Gabor filter is applied to each pixel location in the image. 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.

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

3.2 METHODOLOGY

This section describes the methods for constructing a series of image enhancement techniques for fingerprint images. The algorithm consists of the following stages:

- Normalization,
- Orientation estimation,
- Ridge frequency estimation,
- Gabor filtering.

In this section, I will discuss the methodology for each stage of the enhancement algorithm, including any modifications that have been made to the original techniques.

3.2.1 Normalization:

The next step in the fingerprint enhancement process is image normalization. Normalization is used to standardize the intensity values in an image by adjusting the range of grey-level values so that it lies within a desired range of values.

Let $I(i, j)$ represent the grey-level 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:

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

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

3.2.2 Orientation estimation:

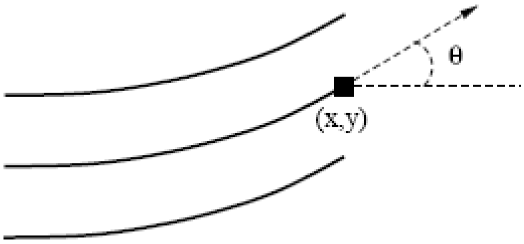


Figure 3.1: The orientation of a ridge pixel in a fingerprint.

The orientation field of a fingerprint image defines the local orientation of the ridges contained in the fingerprint (see Figure 2.1). The orientation estimation is a fundamental step in the enhancement process as the subsequent Gabor filtering stage relies on the local orientation in order to effectively enhance the fingerprint image. The least mean square estimation method employed by Hong et al. is used to compute the orientation image. However, instead of estimating the orientation block-wise, I have chosen to extend their method into a pixel-wise scheme, which produces a finer and more accurate estimation of the orientation field. The steps for calculating the orientation at pixel (i, j) are as follows:

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

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

$$\begin{pmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{pmatrix}.$$

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

$$\begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix}.$$

3. The local orientation at pixel (i, j) can then be estimated using the following

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

$$v_y(i,j) = \sum_{u=i-\frac{w}{2}}^{i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{j+\frac{w}{2}} (\partial^2{}_x(u,v)\partial^2{}_y(u,v)),$$

$$\theta(i,j) = \frac{1}{2}\tan^{-1}\left[\frac{v_x(i,j)}{v_y(i,j)}\right],$$

Where $\theta\,(i, j)$ is the least square estimate of the local orientation at the block centered at pixel (i, j).

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

$$\phi_x(i,j) = \cos(2\theta(i,j)),$$
$$\varphi_y(i,j) = \sin(2\theta(i,j)),$$

where ϕ_x and ϕ_y are the x and y components of the vector field, respectively. After the vector field has been computed, Gaussian smoothing is then performed as follows:

$$\phi'_x(i,j) = \sum_{u=-w_\phi/2}^{w_\phi/2} \sum_{v=-w_\phi/2}^{w_\phi/2} G(u,v)\phi_x(i-uw, j-vw),$$
$$\phi'_y(i,j) = \sum_{u=-w_\phi/2}^{w_\phi/2} \sum_{v=-w_\phi/2}^{w_\phi/2} G(u,v)\phi_y(i-uw, j-vw),$$

where *G* is a Gaussian low-pass filter of size *w*© x *w*©.

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

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

3.2.3 Ridge frequency estimation

In addition to the orientation image, another important parameter that is used in the construction of the Gabor filter is the local ridge frequency. The frequency image represents the local frequency of the ridges in a fingerprint. The first step in the frequency estimation stage is to divide the image into blocks of size *W x W*. The next step is to project the grey-level values of all the pixels located inside each block along a direction orthogonal to the local ridge orientation. This projection forms an almost sinusoidal-shape wave with the local minimum points corresponding to the ridges in the fingerprint. An example of a projected waveform is shown in Figure 2.2.

I have modified the original frequency estimation stage used by Hong et al. to include an additional projection smoothing step prior to computing the ridge spacing. This involves smoothing the projected waveform using a Gaussian low pass filter of size *w x w* to reduce the effect of noise in the projection. The ridge spacing $S(i, j)$) is then computed by counting the median number of pixels between consecutive minima points in the projected waveform. Hence, the ridge frequency $F(i, j)$ for a block centred at pixel (i, j) is defined as:

$$F(i,j) = \frac{1}{S(i,j)},$$

Given that the fingerprint is scanned at a fixed resolution, then ideally the ridge frequency values should lie within a certain range. However, there are cases where a valid frequency value cannot be reliably obtained from the projection. Examples are when no consecutive peaks can be detected from the projection, and also when minutiae points appear in the block.

For the blocks where minutiae points appear, the projected waveform does not produce a well-defined sinusoidal shape wave, which can lead to an inaccurate estimation of the ridge frequency. Thus, the out of range frequency values are interpolated using values from neighbouring blocks that have a well-defined frequency.

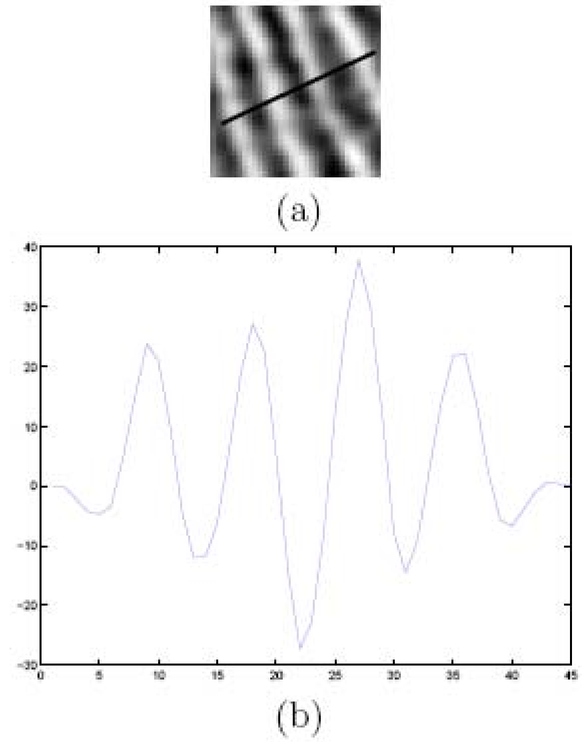


Figure 3.2: The projection of the intensity values of the pixels along a direction orthogonal to the local ridge orientation. (a) A 32 x 32 block from a fingerprint image.
(b) The projected waveform of the block.

3.2.4 Gabor filtering

Once the ridge orientation and ridge frequency information has been determined, these parameters are used to construct the even-symmetric Gabor filter. A two dimensional Gabor filter consists of a sinusoidal plane wave of a particular orientation and frequency, modulated by a Gaussian envelope . Gabor filters are employed because they have frequency-selective and orientation-selective properties. These properties allow the filter to be tuned to give maximal response to ridges at a specific orientation and frequency in the fingerprint image. Therefore, a properly tuned Gabor filter can be used to effectively preserve the ridge structures while reducing noise.

The even-symmetric Gabor filter is the real part of the Gabor function, which is given by a cosine wave modulated by a Gaussian (see Figure 2.3). An even symmetric Gabor filter in the spatial domain is defined as :

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

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

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

where θ is the orientation of the Gabor filter, f is the frequency of the cosine wave, σ_x and σ_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.

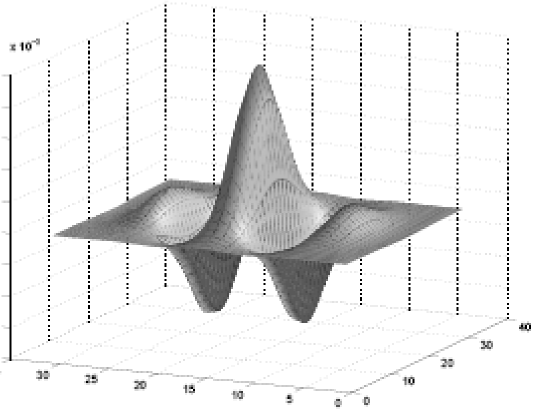


Figure 3.3: An even-symmetric Gabor filter in the spatial domain.

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:

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

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 filter bandwidth, which specifies the range of frequency the filter responds to, is determined by the standard deviation parameters σ_x and σ_y. Since the bandwidth of the filter is tuned to match the local ridge frequency, then it can be deduced that the parameter selection of σ_x and σ_y should be related with the ridge frequency. However, in the original algorithm by Hong et al., σ_x and σ_y were empirically set to fixed values of 4.0 and 4.0, respectively.

A drawback of using fixed values is that it forces the bandwidth to be constant, which does not take into account the variation that may occur in the values of the ridge frequency. For example, if a filter with a constant bandwidth is applied to a fingerprint image that exhibits significant variation in the frequency values, it could lead to non-uniform enhancement or other enhancement artefacts. Thus, rather than using fixed values, I have chosen the values of σ_x and σ_y to be a function of the ridge frequency parameter, which are defined as:

$$\sigma_x = k_x F(i,j),$$
$$\sigma_y = k_y F(i,j),$$

where F is the ridge frequency image, k_x is a constant variable for σ_x, and k_y is a constant variable for σ_y. This allows a more adaptable approach to be used, as the values of σ_x and σ_y can now be specified adaptively according to the local ridge frequency of the fingerprint image.

Furthermore, in the original algorithm, the width and height of the filter mask were both set to fixed values of 11. The filter size controls the spatial extent of the filter, which ideally should be able to accommodate the majority of the useful Gabor waveform information. However, a fixed filter size is not optimal in that it does not allow the accommodation of Gabor waveforms of different sized bandwidths. Hence, to allow the filter size to vary according to the bandwidth of the Gabor waveform, I have set the filter size to be a function of the standard deviation parameters:

$$w_x = 6\sigma_x$$
$$w_y = 6\sigma_y$$

where w_x and w_y are the width and height of the Gabor filter mask, respectively, and σ_x and σ_y are the standard deviations of the Gaussian envelope along the x and y axes, respectively. In the above equation, the width and height of the filter mask are both specified as 6σ, due to most of the Gabor wave information being contained within the region [-3σ;

3σ] away from the y axis. Hence, this selection of parameters allows the filter mask to capture the majority of the Gabor waveform information.

3.3 MINUTIAE EXTRACTION:

After a fingerprint image has been enhanced, the next step is to extract the minutiae from the enhanced image. Following the extraction of minutiae, a final image postprocessing stage is performed to eliminate false minutiae. This chapter provides discussion on the methodology and implementation of techniques for minutiae extraction and fingerprint image postprocessing. The first section contains a review of existing literature in the field of minutiae extraction and postprocessing. The next section discusses the methodology for implementing each of these two techniques. The last section presents the results from the experiments conducted using the implemented techniques.

3.3.1 Basic Process:

The basic algorithm performed minutiae extraction using the skeleton image. The approach involves using a 3 x3 window to examine the local neighborhood of each ridge pixel in the image. A pixel is then classified as a ridge ending if it has only one neighboring ridge pixel in the window, and classified as a bifurcation if it has three neighboring ridge pixels.

Neighborhood pixels	Property of the minutiae point
1	Ridge Ending
3	Ridge Bifurcation
2,4,5,6,7,8	False Minutiae

Table 3.1 Neighborhood pixels and their properties of minutiae points

3.4 SIMULATION RESULTS:

Figure 3.4.1 **Input Fingerprint**

Figure 3.4.2 **Normalized fingerprint**

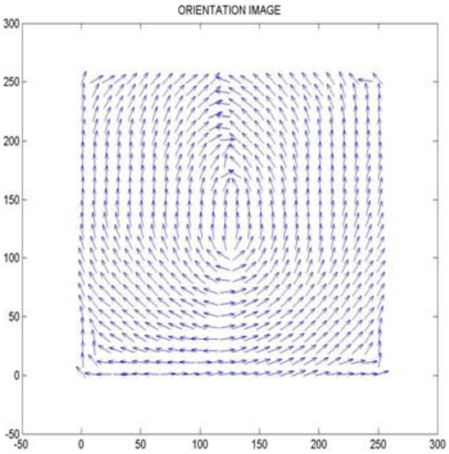


Figure 3.4.3 **Orientation Image**

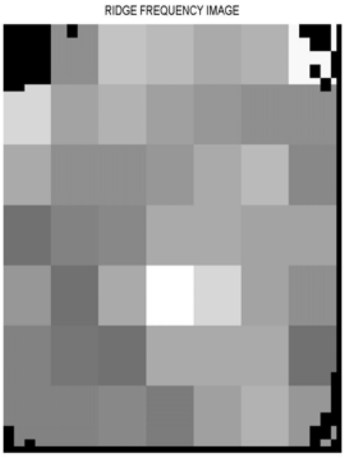


Figure 3.4.4 **Frequency Image**

Figure 3.4.5 **Filtered Image**

Figure 3.4.6 **Binarized Enhanced Image**

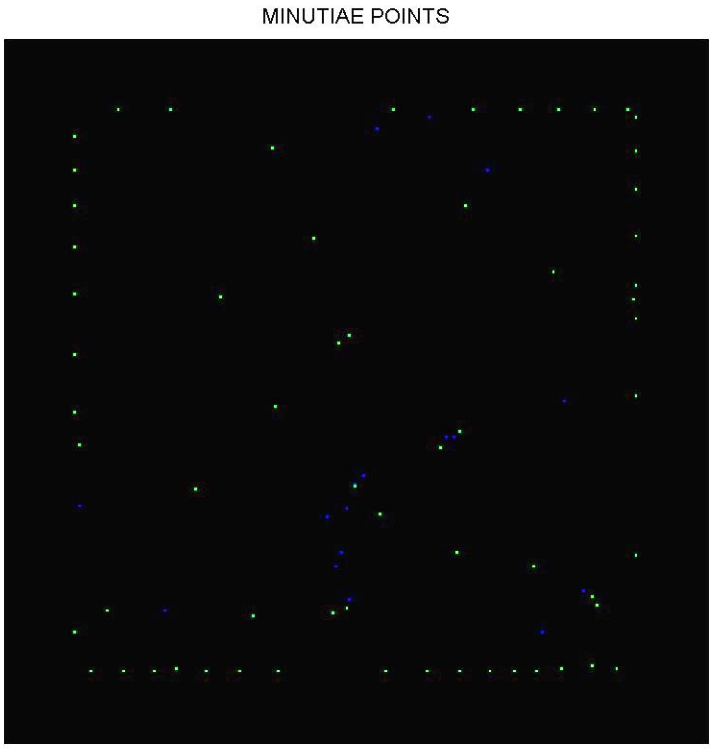
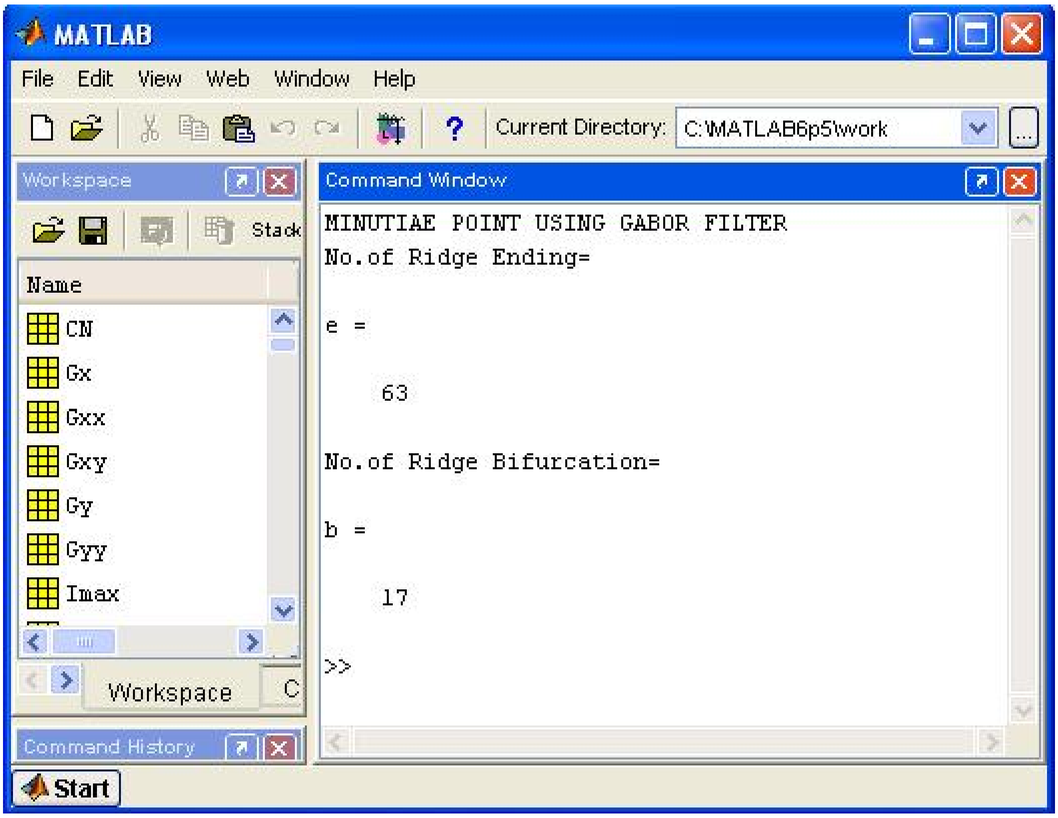


Figure 3.4.7 **Minutiae Point (a) Green= Ridge Endings**
(b) Blue= Ridge Bifurcations



```
MINUTIAE POINT USING GABOR FILTER
No.of Ridge Ending=

e =

    63

No.of Ridge Bifurcation=

b =

    17

>>
```

Figure 3.4.8. **No of Minutiae Point in Matlab Window**

Chapter 4

FINGER PRINT IMAGE ENHANCEMENT ALGORITHM IN WAVELET DOMAIN AND MINUTIAE EXTRACTION

Enhancement in Wavelet domain
Algorithm
Minutiae Extraction using Crossing-Number Concept

FINGERPRINT ENHANCEMENT IN WAVELET DOMAIN

4.1. ENHANCEMENT IN WAVELET DOMAIN

In gray-level fingerprint image, ridge and valley in a local neighborhood form a sinusoidal-shaped plane wave, which has well defined Orientation and Frequency. Hong proposed an effective enhancement method based on Gabor filter in spatial domain. Gabor Filter have optimal joint resolution in both spatial and frequency domains.

Problem with the Existing Algorithm:

Gabor-based enhancement algorithm is focused on the characteristics of local ridge orientation and frequency simultaneity in spatial domain for improving the quality of fingerprint image, but estimation of local ridge orientation is often effected by noise. So the orientation estimation is not reliable in inking regions.

So I proposed an Enhancement algorithm based on Gabor filter in Wavelet Domain. This algorithm uses the Approximation of sub-image and original image have the similar static information. Fingerprint Approximation sub-image contain fewer noises, so the orientation estimated in approximation is more reliable.

4.2 ALGORITHM:

The main steps in the proposed algorithm include:

1. Segmentation
2. Normalization
3. Wavelet Decomposition
4. Ridge Orientation Estimation
5. Frequency Estimation
6. Gabor Filtering
7. Wavelet Reconstruction
8. Binarization and Thinning

4.2.1. Segmentation:

The first step of the fingerprint enhancement algorithm is image segmentation. Segmentation is the process of separating the foreground regions in the image from the background regions. The foreground regions correspond to the clear fingerprint area containing the ridges and valleys, which is the area of interest. The background corresponds to the regions outside the borders of the fingerprint area, which do not contain any valid fingerprint information. When minutiae extraction algorithms are applied to the background regions of an image, it results in the extraction of noisy and false minutiae. Thus, segmentation is employed to discard these background regions, which facilitates the reliable extraction of minutiae.

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

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

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

4.2.2. Normalization:

The process of fingerprint Normalization can reduce the variance in gray-level values along the ridge and valleys by means of adjust the gray level values to the predefined constant mean and variance. And normalization can remove the influences of sensor noise and gray-level deformation. Let $I(n_1,n_2)$ denote the gray-level value at pixel (i , j) in acquired image, the size of fingerprint image m x n, $MandV$ are the estimated mean and variance of input fingerprint image, respectively, and N(i,j) denote the normalized gray-level value at pixel (i,j). The normalized image is defined as fallows:

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

Where $M_0 and V_0$ are the expected mean and variance values respectively. Normalization is pixel-wise operation and does not change the ridge and valley structures.

4.2.3. Wavelet Decomposition:

The Normalized image is into one Approximation and three detail Sub-images. The Approximation and original fingerprint’s pixels have the similar static information and their orientation is similar too. Only approximation coefficient image is used to determine the ridge orientation.

The wavelet transform is implemented by a pyramidal algorithm. The choice of wavelet base filter is essential. The details sub-image of Daubechies wavelet has less information than that of Haar wavelet. And Daubechies wavelet has the compactness. Here for the implementation being I Used **db7** wavelet. The normalized fingerprint image is treated as input signal and decomposed into one Approximation sub-image and three directional coefficient sub-images.

4.2.4. Ridge Orientation Estimation:

The ridge orientation is an intrinsic property of the fingerprint image and the pixels, which are in a local neighborhood, have the same orientations. The algorithm to estimate the orientation in wavelet domain has the fallowing steps:

1. Divide the approximation sub-image into non-overlapping blocks of size $w \times w$;
2. Compute the gradients $G_x(i, j) and G_y(i, j)$ at each pixel (i, j) in each block;
3. Estimate the local orientation of each block center at pixel using the fallowing equations:

$$V_x(i, j) = \sum_{u=i-\frac{w}{2}}^{i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{j+\frac{w}{2}} 2G_x(u,v)G_y(u,v)$$

$$V_y(i, j) = \sum_{u=i-\frac{w}{2}}^{i+2\frac{w}{}} \sum_{v=j-\frac{w}{2}}^{j+\frac{w}{2}} (G^2{}_x(u,v) - G^2{}_y(u,v))$$

$$\hat{\theta}(i, j) = \frac{1}{2}\tan^{-1}\left(\frac{V_x(i, j)}{V_y(i, j)}\right)$$

Estimating the local orientation of approximation image can reduce the influence of detail information, so the orientations are more reliable. Because of the corresponding of approximation and detail sub-image pixel, the approximation sub-image's pixel orientation is regarded as the corresponding pixel's orientation of details sub-images. The size of the approximation sub-image is quarter of the original fingerprint image's size, so the time used in estimating orientation may be reduced.

4.2.5. Ridge Frequency Estimation:

In addition to the orientation image, another important parameter that is used in the construction of the Gabor filter is the local ridge frequency. The frequency image represents the local frequency of the ridges in a fingerprint. The first step in the frequency estimation stage is to divide the image into blocks of size *W x W*. The next step is to project the grey-level values of all the pixels located inside each block along a direction orthogonal to the local ridge orientation. This projection forms an almost sinusoidal-shape wave with the local minimum points corresponding to the ridges in the fingerprint. An example of a projected waveform is shown in Figure 2.2.

I have modified the original frequency estimation stage used by Hong et al. to include an additional projection smoothing step prior to computing the ridge spacing. This involves smoothing the projected waveform using a Gaussian low pass filter of size *w x w* to reduce the effect of noise in the projection. The ridge spacing $\mathrm{S}(i, j)$) is then computed by counting the median number of pixels between consecutive minima points in the projected waveform. Hence, the ridge frequency $F(i, j)$ for a block centered at pixel (i, j) is defined as:

$$F(i, j) = \frac{1}{S(i, j)}, \qquad (2.13)$$

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

4.2.6. Gabor Filtering

Orientation and frequency of parallel ridges and valleys are fingerprint image's intrinsic properties. Gabor Filter has both orientation-selective and frequency-selective properties and has optimal joint resolution in both spatial and frequency domains. So Gabor filter may remove the noise and preserve true ridge/valley structures.

The Even-symmetric Gabor filter has the fallowing form:

$$h(x, y, \varphi, f) = \exp\left\{-\frac{1}{2}\left[\frac{x^2{}_\varphi}{\delta^2{}_x} + \frac{y^2{}_\varphi}{\delta^2{}_y}\right]\right\}\cos(2\pi f x_\varphi)$$

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

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

Where φ the orientation of the Gabor filter is, f is the frequency of a sinusoidal of plane wave, δ_x and δ_y are the space constants of the Gaussian envelope along x and y axes, respectively.

The detail Sub-images are not only contain noises, but also include a number of detail information, so the enhancement algorithm can't ignore all detail information, but enhance the detail information along ridge orientation.

Let the approximation sub-image of fingerprint is $L(i, j)$, detail sub-images are $H(i, j)$, $V(i, j)$ and $V(i, j)$, respectively, where $i = 1,2,\ldots, M/2$, $j = 1,2,..., N/2$. $\overset{\Lambda}{\theta}(i, j)$ is the orientation of $L(i, j)$, which is estimated by orientation process.

The enhanced image $EL(i, j)$ of approximation sub-image is computed as fallows:

$$EL(i, j) = \sum_{u=-\frac{w_g}{2}}^{\frac{w_g}{2}} \sum_{v=-\frac{w_g}{2}}^{\frac{w_g}{2}} h(u, v, \overset{\Lambda}{\theta}(i, j), f)L(i-u, j-v)$$

Based on the hierarchical relationship of 2D wavelet transform, all the detail sub-images are enhanced by reference to the related location's local orientation $\overset{\Lambda}{\theta}(i, j)$ of the approximation sub-images. We can compute the enhanced detail sub-imaged $EH(i, j)$ according to the above equation replacing the $L(i-u, j-v)$ by $H(i-u, j-v)$, $V(i-u, j-v)$ and $D(i-u, j-v)$, respectively.

4.2.7. Wavelet Reconstruction:

After getting $EL(i, j), EH(i, j), EV(i, j)$ and $ED(i, j)$, finally the enhanced fingerprint image is obtained by using Wavelet Reconstruction i.e. Wavelet Inverse Transform.

4.2.8. Binarization and Thinning

Most minutiae extraction algorithms operate on binary images where there are only two levels of interest: the black pixels that represent ridges, and the white pixels that represent valleys. Binarization is the process that converts a grey level image into a binary image. This improves the contrast between the ridges and valleys in a fingerprint image, and consequently facilitates the extraction of minutiae.

One useful property of the Gabor filter is that it has a DC component of zero, which means the resulting filtered image has a mean pixel value of zero. Hence, straightforward binarization of the image can be performed using a global threshold of zero. The binarization process involves examining the grey-level value of each pixel in the enhanced image, and, if the value is greater than the global threshold, then the pixel value is set to a binary value one; otherwise, it is set to zero. The outcome is a binary image containing two levels of information, the foreground ridges and the background valleys.

The final image enhancement step typically performed prior to minutiae extraction is thinning. Thinning is a morphological operation that successively erodes away the foreground pixels until they are one pixel wide. A standard thinning algorithm [7] is employed, which performs the thinning operation using two sub-iterations. This algorithm is accessible in MATLAB via the `thin' operation under the **bwmorph** function. Each sub-iteration begins by examining the neighborhood of each pixel in the binary image, and based on a particular set of pixel-deletion criteria, it checks whether the pixel can be deleted or not. These sub-iterations continue until no more pixels can be deleted.

The application of the thinning algorithm to a fingerprint image preserves the connectivity of the ridge structures while forming a skeletonised version of the binary image. This skeleton image is then used in the subsequent extraction of minutiae. The process involving the extraction of minutiae from a skeleton image will be discussed in the next chapter.

4.3. MINUTIAE EXTRACTION USING CROSSING - NUMBER CONCEPT:

After a fingerprint image has been enhanced, the next step is to extract the minutiae from the enhanced image. This chapter provides discussion on the methodology and implementation of techniques for minutiae extraction and fingerprint. The first section contains a review of existing literature in the field of minutiae extraction. The next section discusses the methodology for implementing technique. The last section presents the results from the experiments conducted using the implemented techniques.

4.3.1 Crossing-Number Concept:

The most commonly employed method of minutiae extraction is the Crossing-Number (CN) concept. This method involves the use of the skeleton image where the ridge flow pattern is eight-connected. The minutiae are extracted by scanning the local neighborhood of each ridge pixel in the image using a 3x3 window. The CN value is then computed, which is defined as half the sum of the differences between pairs of adjacent pixels in the eight-neighborhood.

Using the properties of the CN as shown in Table 3.1, the ridge pixel can then be classified as a ridge ending, bifurcation or non-minutiae point. For example, a ridge pixel with a CN of one corresponds to a ridge ending, and a CN of three corresponds to a Bifurcation.

CN	Property
0	Isolated point
1	Ridge ending point
2	Continuing ridge point
3	Bifurcation point
4	Crossing point

Table 4.1: Properties of the Crossing Number.

4.3.2 Methodology

The Crossing Number (CN) method is used to perform minutiae extraction. This method extracts the ridge endings and bifurcations from the skeleton image by examining the local neighborhood of each ridge pixel using a 3x3 window. The CN for a ridge pixel *P* is given by:

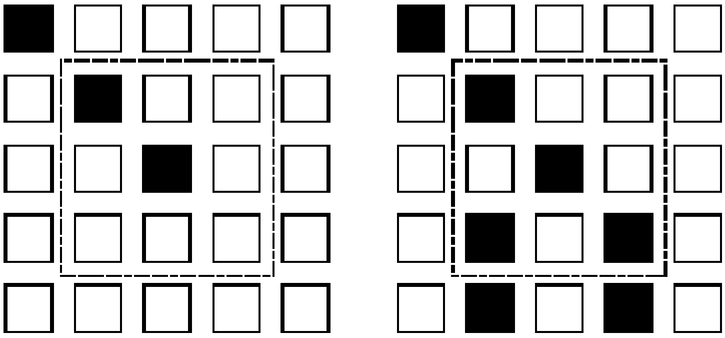
$$CN = 0.5\sum_{i=1}^{8}\left|P_i - P_{i+1}\right|, \qquad P_9 = P_1 \qquad (3.1)$$

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 3.2, a ridge pixel with a CN of one corresponds to a ridge ending, and a CN of three corresponds to a bifurcation.
For each extracted minutiae point, the following information is recorded:

- *x* and *y* coordinates,
- orientation of the associated ridge segment, and
- type of minutiae (ridge ending or bifurcation).



(a) CN = 1 (b) CN = 3

Figure 4.3.1: Examples of a ridge ending and bifurcation pixel. (a) A Crossing Number of one corresponds to a ridge ending pixel. (b) A Crossing Number of three corresponds to a bifurcation pixel.

4.4 SIMULATION RESULTS:

Figure 4.4.1 **Input Fingerprint**

Figure 4.4.2 **Segmented Image**

Figure 4.4.3 **Normalized Image.**

Figure 4.4.4 **Wavelet decomposed fingerprint**

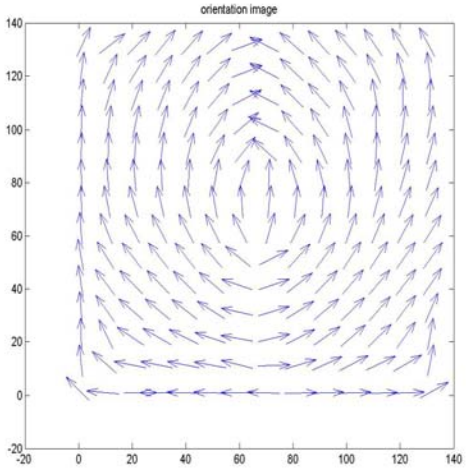


Figure 4.4.5 **Orientation Image**

Figure 4.4.6 **Enhanced Image**

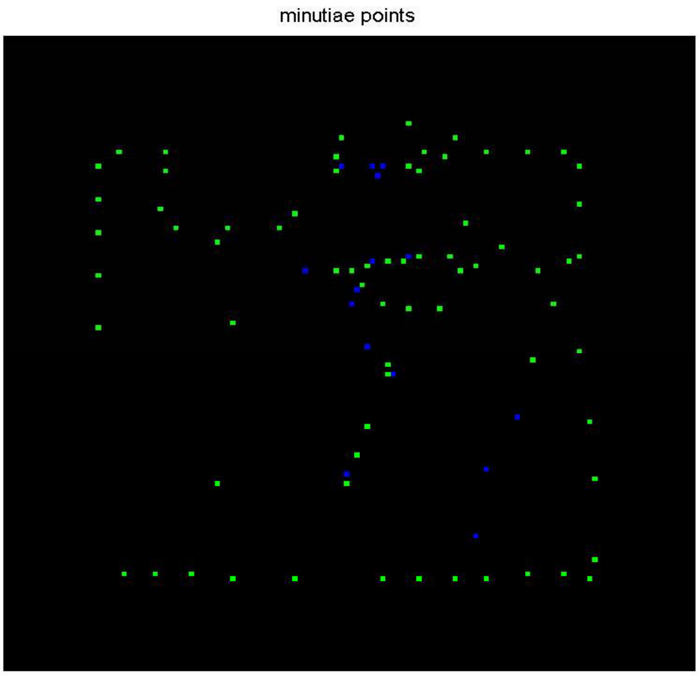
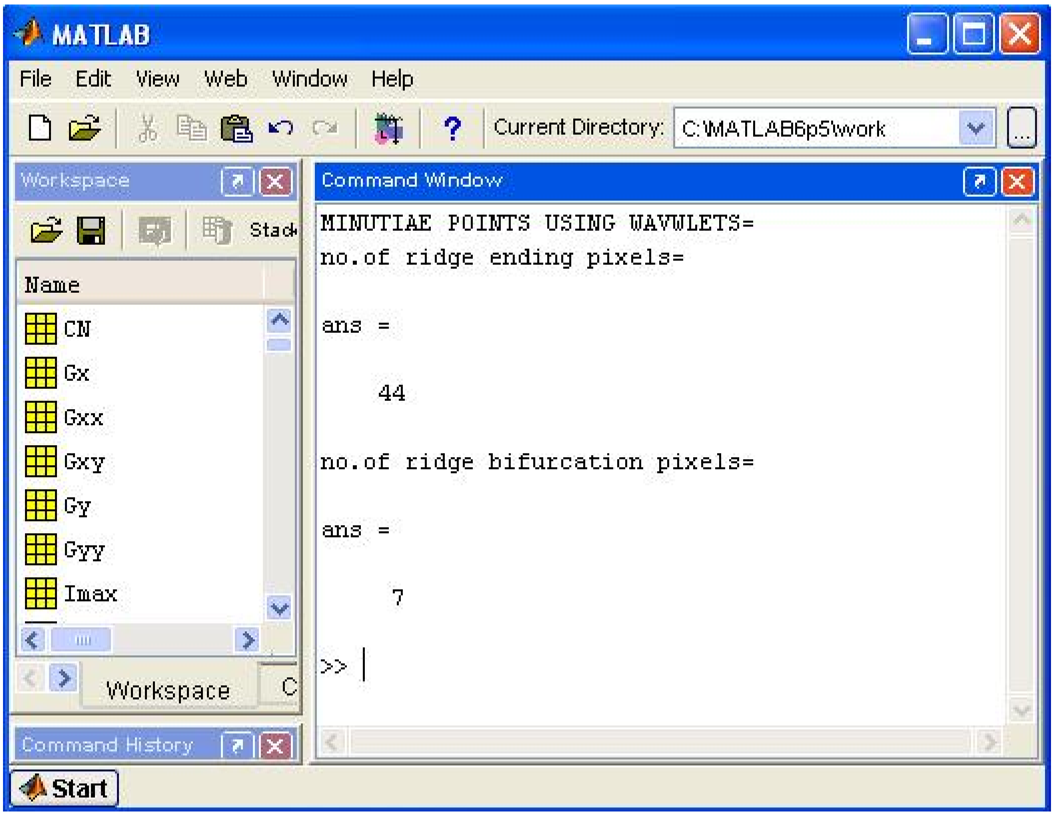


Figure 4.4.7 **Minutiae Points (a) Green= Ridge Endings**
(b) Blue=Ridge Bifurcations



```
MINUTIAE POINTS USING WAVWLETS=
no.of ridge ending pixels=

ans =

    44

no.of ridge bifurcation pixels=

ans =

     7

>> 
```

Figure 4.4.8 **Minutiae points count in Mat Lab Window**

Chapter 5

CONCLUSION AND FUTURE WORK

CONCLUSION AND FUTURE WORK

In a field like biometrics where the accuracy of the result is given more preference over anything else, it is of utmost importance that the new method that is developed need to be more accurate than the existing methods.

COMPARISON OF THE TECHNIQUES:

The first technique is Binarization method. This method will not at all give the required enhancement and this technique is not suitable for extracting minutiae from enhanced image.

In the second method the improvement is done by introduction of Gabor filters which takes into account both the frequency and orientation of the image and the filtering is done with a greater accuracy.

The Wavelet Transform has been found to be a very effective tool in denoising and Compression techniques. Hence we use it in denoising part of the enhancement stage. It is computationally fast and effective compared to the present techniques of denoising of images.

In the third method the concept of wavelet transform is incorporated into it. The denoising stage is carried out with the help of wavelet transform. The image is decomposed to skeleton level and the denoising is done to this sub image which is comparatively faster than the prevalent algorithms. Moreover the translation of the images into mathematical terms increases the easiness to handle the image more effectively.

Hence a hybrid method was devised to improve the performance of enhancement techniques of fingerprint.

Among the various methods used the proposed algorithm will improve the quality and reduce the false minutiae points as well as time.

For a given Fingerprint Image below The table show the comparison of different Techniques and their time.

Method ⟶	With out Enhancement	Binarization Method	Using Gabor-Filtering Spatial Domain	Proposed Algorithm in wavelet domain
R.E	214	129	63	44
R.B	98	57	17	7
T.T	3.52	2.640	1.957	1.725

Table 5.1: Experimental results RE=Ridge Endings, R.B=Ridge Bifurcations T.T=Total Time.

Conclusion:

Comparing with the existing enhancement algorithm based on Gabor-filter in spatial domain, the proposed algorithm using Gabor filter in Wavelet domain, not only saves the time but also effectively improve the quality of the fingerprint. The proposed minutiae extraction using CN concept will reduce the false minutiae.

Future Work:

An investigation into a filter whose primary aim is to specifically enhance the minutia points. This project has followed the approach adopted by most previous work where the emphasis is on enhancing the ridge structures using Gabor, or Gabor-like filters. However, while the ridge structures are enhanced, this approach has shown to be less effective in enhancing areas containing minutiae points, which are the points of main interest.

After extracting the minutiae points from the fingerprint, we can extend this thesis to fingerprint matching. Then critical part in the fingerprint matching is to extract to features .So this thesis will help in extending to Fingerprint matching as we found out all the minutiae point and properties of the points.

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