FINGERPRINT RECOGNITION: A study on image enhancement and minutiae extraction

A

Thesis Report

Submitted in

partial fulfillment of the requirement for the degree of

Bachelor of Technology in Electronics and Communication Engineering.

by

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CERTIFICATE

National Institute of Technology Rourkela

This is to certify that the thesis entitled, "Fingerprint recognition: A study on image enhancement and minutiae extraction" submitted by Shougaijam Debajit Singh and Shiba Prasad Majhi in partial fulfillments for the requirements for the award of **Bachelor of Technology Degree in Electronics and Communication Engineering**, National Institute of Technology, Rourkela is an authentic work carried out by them is under my supervision.

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CONTENTS

ABSTRACT

Fingerprints are a great source for identification of individuals. Fingerprint recognition is one of the oldest forms of biometric identification. However obtaining a good fingerprint image is not always easy. So the fingerprint image must be preprocessed before matching. The objective of this project is to present a better and enhanced fingerprint image.

We have studied the factors relating to obtaining high performance feature points detection algorithm, such as image quality, segmentation, image enhancement and feature detection. Commonly used features for improving fingerprint image quality are Fourier spectrum energy, Gabor filter energy and local orientation. Accurate segmentation of fingerprint ridges from noisy background is necessary. For efficient enhancement and feature extraction algorithms, the segmented features must be void of any noise.

A preprocessing method consisting of field orientation, ridge frequency estimation, Gabor filtering, segmentation and enhancement is performed. The obtained image is applied to a thinning algorithm and subsequent minutiae extraction. The methodology of image preprocessing and minutiae extraction is discussed. The simulations are performed in the MATLAB environment to evaluate the performance of the implemented algorithms. Results and observations of the fingerprint images are presented at the end.

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Today, we can obtain routine information from dedicated websites, retrieve easily information via search engines, manage our bank accounts and credit information, shop online and bid for products. High security authentication system is necessary for safe access. Traditional password and token based authentication schemes are insecure. Due to the vulnerability of conventional authentication system, cybercrime has increased in the past few years. Identity authentication, which is based on biometric feature such as face, iris, voice, hand geometry, handwriting, retina, fingerprints can significantly decrease the fraud. So they are being replaced by biometric authentication mechanisms.

Among biometrics, fingerprint systems have been one of most widely researched and deployed. Fingerprints are one of the first biometrics to be widely used. It is popular because of their easy access, low price of fingerprint sensors, non-intrusive scanning, and relatively good performance. In recent years, significant performance improvements have been achieved in commercial automatic fingerprint recognition systems.

The fingerprint of every individual is considered to be unique. No two persons have the same set of fingerprints. Also, Finger ridge patterns do not change throughout the life of an individual. This property makes fingerprints an excellent biometric identifier. So it is one of the popular and effective means for identification of an individual and used as forensic evidence.

However, current fingerprint recognition technologies are vulnerable to poor quality images. It is imperative to continue research on improving the reliability, stability, performance and security of fingerprint recognition systems. Low quality fingerprint image, distortion, the partial image problems, large fingerprint databases are all major areas of research needed to improve the accuracy of current systems.

1.2 What is a fingerprint?

Fingerprints are the patterns formed on the epidermis of the fingertip. The fingerprints are of three types: arch, loop and whorl. The fingerprint is composed of ridges and valleys. The interleaved pattern of ridges and valleys are the most evident structural characteristic of a fingerprint. There are three main fingerprint features

a) Global Ridge Pattern
b) Local Ridge Detail
c) Intra Ridge Detail

Fig 1.1 Fingerprint Image

Global ridge detail:

There are two types of ridge flows: the pseudo-parallel ridge flows and high-curvature ridge flows which are located around the core point and/or delta point(s). This representation relies on the ridge structure, global landmarks and ridge pattern characteristics.

The commonly used global fingerprint features are:

i) singular points – They are discontinuities in the orientation field. There are two types of singular points- core and delta. A core is the uppermost of a curving ridge, and a delta point is the point where three ridge flows meet. They are used for fingerprint registration and classification.

ii) ridge orientation map – They are local direction of the ridge-valley structure. It is helpful in classification, image enhancement, feature verification and filtering.

ii) ridge frequency map – They are the reciprocal of the ridge distance in the direction perpendicular to local ridge orientation. It is used for filtering of fingerprint images.

Local Ridge Detail:

This is the most widely used and studied fingerprint representation. Local ridge details are the discontinuities of local ridge structure referred to as minutiae. They are used by forensic experts to match two fingerprints. There are about 150 different types of minutiae. Among these minutiae types, ridge ending and ridge bifurcation are the most commonly used as all the other types of minutiae are combinations of ridge endings and ridge bifurcations.

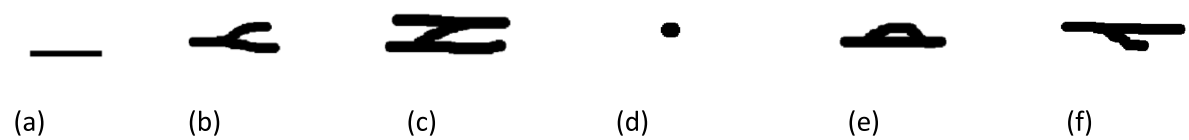


Fig 1.2 Types of minutiae

The minutiae are relatively stable and robust to contrast, image resolutions, and global distortion when compared to other representations. Although most of the automatic fingerprint recognition systems are designed to use minutiae as their fingerprint representations, the location information and the direction of a minutia point alone are not sufficient for achieving high performance. Minutiae-derived secondary features are used as the relative distance and radial angle are invariant with respect to the rotation and translation of the fingerprint.

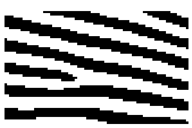
Intra Ridge Detail

On every ridge of the finger epidermis, there are many tiny sweat pores and other permanent details. Pores are distinctive in terms of their number, position, and shape. However, extracting pores is feasible only in high-resolution fingerprint images and with very high image quality. Thus the cost is very high. Therefore, this kind of representation is not adopted by current automatic fingerprint identification systems (AFIS).

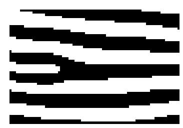
1.2 Fingerprint recognition

Fingerprint recognition is one of the popular biometric techniques. It refers to the automated method of verifying a match between two fingerprint images. It is mainly used in the identification of a person and in criminal investigations. It is formed by the ridge pattern of the finger. Discontinuities in the ridge pattern are used for identification. These discontinuities are known as minutiae. For minutiae extraction type, orientation and location of minutiae are extracted.

Two features of minutiae are used for identification: termination and bifurcation.



(a) Ridge ending



(b) Bifurcation

Fig 1.3 Types of local ridge features

The advantages of fingerprint recognition system are

(a) They are highly universal as majority of the population have legible fingerprints.
(b) They are very reliable as no two people (even twins) have same fingerprint.
(c) Fingerprints are formed in the fetal stage and remain structurally unchanged throughout life.
(d) It is one of the most accurate forms of biometrics available.
(e) Fingerprint acquisition is non intrusive and hence is a good option .

1.3 Approach

There are two approaches for fingerprint recognition. They are image based approach, texture based approach and minutiae based approach.

In image based matching, the image itself is used as the template. It requires only low resolution images. Matching is done by optical correlation and is extremely fast. It is based on the global features of a whole fingerprint image. However it requires accurate alignment of the fingerprint samples and is not favorable for changes in scale, orientation and position.

The second is the texture based approach. It uses texture information for matching and performs well with poor quality prints. However like image based matching it requires accurate alignment of the two prints and not invariant to translation, orientation and non-linear distortion.

Minutiae-based approach is the last approach. Here the ridge features called minutiae are extracted and stored in a template for matching. It is invariant to translation, rotation and scale changes. It is however error prone in low quality images.

The minutiae based approach is applied. Usually before minutiae extraction, image preprocessing is performed. In our project we have focused mainly on the preprocessing and extraction stage. Fingerprint enhancements techniques are used to reduce the noise and improve the clarity of ridges against valleys.

The image preprocessing consists of the following stages. They are field orientation, ridge frequency estimation, image segmentation and image enhancement thinning. It is followed by a minutiae extraction algorithm which extracts the main minutiae features required for matching of two samples.

CHAPTER 2

IMAGE ACQUISITION

2.1 Image Acquisition

Image acquisition is the first step in the approach. It is very important as the quality of the fingerprint image must be good and free from any noise. A good fingerprint image is desirable for better performance of the fingerprint algorithms.

Based on the mode of acquisition, a fingerprint image may be classified as off-line or live-scan. An off-line image is typically obtained by smearing ink on the fingertip and creating an inked impression of the fingertip on paper. A live-scan image, on the other hand, is acquired by sensing the tip of the finger directly, using a sensor that is capable of digitizing the fingerprint on contact. Live-scan is done using sensors. There are three basic types of sensors used. They are optical sensors, ultrasonic sensors and capacitance sensors.

Optical sensors capture a digital image of the fingerprint. The light reflected from the finger passes through a phosphor layer to an array of pixels which captures a visual image of the fingerprint. Ultrasonic sensors use very high frequency sound waves to penetrate the epidermal layer of skin. The sound waves are generated using piezoelectric transducers. The reflected wave measurements can be used to form an image of the fingerprint. Electrical charges are created between the surface of the finger and each of the silicon plates when a finger is placed on the chip. The magnitude of these electrical charges depends on the distance between the fingerprint surface and the capacitance plates. Thus fingerprint ridges and valleys result in different capacitance patterns across the plates. An accurate capacitance measurement is quite difficult to make and adjust, and each vendor has its own method to get enough sensitivity to make a difference between the ridges and the valleys. Of these optical sensors is the most widely use. They have high efficiency and acceptable accuracy.

CHAPTER 3

FINGERPRINT IMAGE ENHANCEMENT

3.1 Introduction

The performance of minutiae extraction algorithms and other fingerprint recognition techniques relies heavily on the quality of the input fingerprint images. In an ideal fingerprint image, ridges and valleys alternate and flow in a locally constant direction. However the fingerprint images obtained are usually poor due to elements that corrode the clarity of the ridge elements. This leads to problems in minutiae extraction. Thus, image enhancement techniques are employed to reduce the noise and enhance the definition of ridges against valleys. In order to ensure good performance of the ridge and minutiae extraction algorithms in poor quality fingerprint images, an enhancement algorithm to improve the clarity of the ridge structure is necessary.

A fingerprint image contains regions of different quality. They are

a) well-defined region

b) recoverable region

c) unrecoverable region.

Well-defined regions, recoverable regions and unrecoverable regions may be identified according to image contrast, orientation consistency, ridge frequency, and other local features. The goal of an enhancement algorithm is to improve the clarity of the ridge structures in the recoverable regions and mark the unrecoverable regions as too noisy for further processing. The input of the enhancement algorithm is a gray-scale image. The output may either be a gray-scale or a binary image.

There are five stages in image enhancement:

a) Segmentation
b) Normalization
c) Orientation Estimation
d) Ridge Frequency Estimation
e) Gabor Filtering

Segmentation is performed to enhance the foreground regions. Normalization allows the image to have a set of gray values. Orientation estimation and ridge frequency estimation are applied for proper Gabor filtering. Gabor Filter finally removes the noise inside the image. Thus the image is fully enhanced and can be used for feature extraction.

3.2 Segmentation

Image segmentation is the first step in the in the enhancement algorithm. Image segmentation is used to locate objects and boundaries like lines, curves in images. In a fingerprint image there are foreground regions and the background regions .The foreground regions show the ridges and valleys while the background regions are to be left out. The foreground regions have a high variance value while the background regions have low values. Segmentation separates the foreground regions from the background image for reliable extraction of minutiae.

The image is divided into blocks. For each block the gray scale variance is calculated. If the value is lower than the global threshold it is assigned to the background else it is assigned to the foreground.

Let V(k) be the variance for a block of size W×W. Then

$$V(k) = 1/W^2 \sum_{i=0}^{W-1} \sum_{j=0}^{W-1} (I(i,j) - M(k))^2 \qquad (3.1)$$

Where I(i.j) is the grey scale value at pixel(i,j) and M(k) is the mean gray value.

The variance threshold separates the foreground regions from the background regions. The foreground regions that are segmented are the areas having the ridge structures. The remaining regions are untouched. However the threshold must be given properly. If the threshold value is too large, foreground regions may be incorrectly assigned as background regions. Conversely, if the threshold value is too small, background regions may be assigned as part of the fingerprint foreground area. A variance threshold of around 100 has been found to give optimal results in terms of differentiating the foreground and background regions.

3.3 Normalization

It is the next step in the enhancement algorithm. Normalization is done so that the gray level values lies within a given set of values. The fingerprint image is normalized to have a predefined mean and variance. This is required as the image usually has distorted levels of gray values among the ridges and the valleys. Normalization allows to standardize the distorted levels of variation in the gray scale values. Normalization involves pixel-wise operations and does not change the ridge and valley structures.

Normalization is a linear process. Suppose the intensity range of the image is 50 to 180 and the desired range is 0 to 255 the process entails subtracting 50 from each of pixel intensity, making the range 0 to 130. Each pixel intensity is multiplied by 255/130, making the range 0 to 255.

The normalized image is given by

$$N(i,j) = \begin{cases} M_0 + \sqrt{V_0 (I(i,j) - M)^2 / V} & \text{if } I(i,j) > M \\ M_0 - \sqrt{V_0 (I(i,j) - M)^2 / V} & \text{otherwise} \end{cases} \quad (3.2)$$

Where for a pixel I(i,j) the estimated mean and variances are M and V respectively. M_0 and V_0 denote the desired mean and variance values.

Histogram equalization, as normalization method, is a process to enhance the contrast of images by transforming its intensity values. Usually a fingerprint image has different gray values for every pixel. It is desirable to have the gray value around a mean value. This is achieved by histogram equalization. It increases the local contrast of images. Thus the intensities can be distributed on the histogram. This allows for areas of lower local contrast to gain a higher contrast without affecting the global contrast. Histogram equalization accomplishes this by effectively spreading out the intensity values.

The histogram of the original image illustrates that all the intensity values lie on the right hand side of the 0–255 scale, with no pixels in the left hand side. The histogram of the normalised image shows that the range of intensity values has been adjusted such that there is a more balanced distribution between the dark and light pixels. Normalising the image improves the contrast between the ridges and valleys. It does not alter the shape of the original histogram plot. The relative position of the values along the *x* axis is shifted.

3.4 Ridge Orientation estimation

The next step is calculation of orientation image. Orientation calculation is critical for fingerprint image enhancement and restoration in both frequency and spatial domain. The orientation image represents the local orientation of the ridges and is a matrix of direction vectors. It is important as Gabor filtering depends on the proper orientation.

Most of the fingerprint classification and identification processes calculate the local ridge orientation of the fixed-size block instead of each pixel. The simplest and most natural approach for extracting local ridge orientation is based on computation of gradients in the fingerprint image. The gradient based approach is used to find the gradient. The gradient is perpendicular to the orientation vector.

Suppose the image is divided in square blocks of 15×15. In each block, frequencies F[i], i = 0...7 for eight directions are calculated. The average frequency is computed. Then the difference between the frequency for each direction and average frequency is calculated. For very pixel the gradient is calculated and standard deviation for the eight directions is calculated. If standard deviation is larger than a threshold, then the direction with the maximum frequency is regarded as the dominant direction. Otherwise, weighted average direction is computed as the dominant direction. The orientation vector for each block can be found out.

For this a block of W×W is chosen. The gradient in the horizontal and vertical directions are found and given by $\partial_x(i,j)$ and $\partial_y(i,j)$.

The local orientation is given by

$$V_x(i,j) = \sum_{p=i-W/2}^{i+W/2} \sum_{q=j-W/2}^{j+W/2} 2\partial_x(p,q)\partial_y(p,q) \qquad (3.3)$$

$$V_y(i,j) = \sum_{p=i-W/2}^{i+W/2} \sum_{q=j-W/2}^{j+W/2} \partial^2_y(p,q)\partial^2_x(p,q) \qquad (3.4)$$

$$\Phi(i,j) = 0.5 \tan^{-1}(V_y/V_x) \qquad (3.5)$$

$\Phi(i,j)$ is the orientation estimation.

The ridges are oriented in a local direction for proper Gabor Filtering. It can produce accurate orientation estimates in the presence of minimal amounts of noise, but its perform deteriorates under high levels of noise.

3.6 Ridge frequency estimation

Local ridge frequency is another important parameter used in the construction of the Gabor filter. The local ridge frequency f_{xy} at point [x, y] is the number of ridges per unit length along a hypothetical segment centered at [x, y] and orthogonal to the local ridge orientation θ_{xy}. A frequency image F, analogous to the orientation image D, can be defined if the frequency is estimated at discrete positions and arranged into a matrix.

The first step in the frequency estimation stage is to divide the image into blocks of size W×W. The next step is to project the gray-level values of all the pixels located inside each block along a direction orthogonal to the local ridge orientation. It forms an almost sinusoidal-shape wave with the local minimum points corresponding to the ridges in the fingerprint. The ridge spacing is calculated by counting the number of pixels between consecutive minima points in the projected waveform.

Let R(i,j) be the ridge spacing. For a block of size W×W, it is calculated by counting number of pixels between minutiae points. Then the ridge frequency F(i,j) is given by

$$F(i,j) = 1/R(i,j) \qquad (3.6)$$

The ridge frequency values are presented in terms of ridge wavelength. The presence of noise leads to the creation of false local minima, which mask out the location of the true minimum points. These false minima can then lead to an inaccurate estimation of the ridge wavelength. Thus the noise needs to be filtered out for proper ridge frequency estimation. The image can now be applied to a Gabor filter. All fingerprints do not exhibit the same average ridge wavelength . Different ridge wavelength values may result from different fingerprints.

3.8 Gabor Filtering

Gabor filter is a linear filter used for edge detection. A Gabor filter is a linear filter whose impulse response is defined by a harmonic function multiplied by a Gaussian function .Gabor filter can be viewed as a sinusoidal plane of particular frequency and orientation, modulated by a Gaussian envelope.

The Gabor filter is represented by

$$G(x, y, \Omega, f) = \exp \{0.5[\, x^2_\theta/\phi^2_x + y^2_\theta/\phi^2_y]\} \cos(2\pi f x_\theta) \quad (3.7)$$

$$x_\theta = x \cos\theta + y \sin\theta \quad (3.8)$$

$$y_\theta = -x \sin\theta + y \sin\theta \quad (3.9)$$

where θ is the orientation of the Gabor filter, f is the frequency of the wave, ϕ_x and ϕ_y are the standard deviations of the Gaussian function and x_θ , y_θ denote the x and y axes of the filter respectively.

Gabor filters have frequency-selective and orientation-selective properties which allow the filter to be tuned to give maximal response to ridges at a specific orientation and frequency in the fingerprint image. Once the ridge orientation and ridge frequency information has been determined, these parameters are used to construct the even-symmetric Gabor filter.

The Gabor filter is applied to the fingerprint image by convoluting the filter and image. For a pixel (i,j), the orientation value and ridge frequency value are required.

In fingerprint enhancement, Gabor filter can be tuned to specific frequency and orientation values. As the ridge orientation and frequency estimation has already been calculated, the Gabor filter can enhances the ridges in the direction of local orientation effectively preserving the ridge structures.The value of ϕ_x determines the degree of contrast enhancement and the value of ϕ_y determines the smoothing of the ridges. A large value will result in blurring of the images whereas a low value would not be effective in removing noise from the images. So a suitable value of ϕ_x and ϕ_y must be taken.

CHAPTER 4

MINUTIAE EXTRACTION

4.1 Introduction

After the enhancement of the fingerprint image, the image is ready for minutiae extraction. For proper extraction, however, a thinning algorithm is applied to the enhanced image. It produces a skeletonised representation of the image. This chapter will deal discuss the methodology and algorithm associated with thinning and feature extraction.

4.2 Thinning

Thinning is a morphological operation that is used to remove selected foreground pixels from binary images. It is used to eliminate the redundant pixels of ridges till the ridges are just one pixel wide. Thinning is normally only applied to binary images, and produces another binary image as output. It is the final step prior to minutiae extraction. It uses an iterative, parallel thinning algorithm. All the pixels on the boundaries of foreground regions that have at least one background neighbor are taken. Any point that has more than one foreground neighbor is deleted as long as doing so does not locally disconnect the region containing that pixel. Iterate until convergence.

The requirements of a good thinning algorithm are

a) The thinned fingerprint image obtained should be of single pixel width.
b) Each ridge must be thinned to its centre pixel.
c) Noise and singular pixels must be eliminated.

The steps are as follows:

(i) Sobel operator is applied to reduce the threshold output of the edge detector.

(i) The image is set at a particular gray level to obtain a binary image.
(ii) The thinning iteration is applied until all lines are one pixel wide.

4.2 Minutiae extraction

After the enhancement of the fingerprint image the next step is minutiae extraction. The method extracts the minutiae from the enhanced image. This method extracts the ridge endings and bifurcations from the skeleton image by examining the local neighborhood of each ridge pixel using a 3×3 window. The method used for minutiae extraction is the crossing number (CN) method. 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 3×3 window. CN is defined as half the sum of the differences between the pairs of adjacent pixel.

The ridge pixel can be divided into bifurcation, ridge ending and non-minutiae point based on it. A ridge ending point has only one neighbor, a bifurcation point possesses more than two neighbors, and a normal ridge pixel has two neighbors. A CN value of zero refers to an isolated point, value of one to a ridge ending, two to a continuing ridge point, three to a bifurcation point and a CN of four means a crossing point. Minutiae detection in a fingerprint skeleton is implemented by scanning thinned fingerprint and counting the crossing number. Thus the minutiae points can be extracted.

A 3×3 window is used. The CN is given by

$$CN=0.5 \sum_{i=1}^{8}(P_i - P_{i+1}) \qquad (4.1)$$

For a pixel q, the eight pixels are scanned in an anti-clockwise direction. The pixel can be classified after obtaining its pixel value. The coordinates, orientation of the ridge segment and type of minutiae of each minutiae point is recorded for each minutiae.

After a successful extraction of minutiae, they are stored in a template, which may contain the minutia position (x,y), minutia direction (angle), minutia type (bifurcation or termination), and in some case the minutia quality may be considered. During the enrollment the extracted template are stored in the database and will be used in the matching process as reference template or database template. During the verification or identification, the extracted minutiae are also stored in a template and are used as query template during the matching.

CHAPTER 5

PROGRAMMING

5.1

Histogram Equalization:

```
f=imread('5.tif');
L=max(max(f));
a=input('Enter the lower range, a = ');
b=input('Enter the higher range, b = ');
al=input('Enter alpha value= ');
be=input('Enter beta value = ');
ga=input('Enter gamma value = ');
va=al*a;
vb=be*(b-a)+va;
[M,N]=size(f);
    for x = 1:M
      for y = 1:N
        if(f(x,y)<a)
          g(x,y)=al*f(x,y);
        elseif(f(x,y)>=a & f(x,y)<b)
            g(x,y)=be*(f(x,y)-a)+va;
        else
            g(x,y)=ga*(f(x,y)-b)+vb;
        end
      end
    end
imshow(f), figure, imshow(g);
```

5.2

Program for segmentation, thinning and minutiae extraction

```
% Image read

I=imread('5.tif');
imshow(I)
set(figure,'position',[1 1 600 600]);

% Image Segmentation

J=I(:,:,1)>160;
imshow(J)
set(figure,'position',[1 1 600 600]);

% Thinning

K=bwmorph(~J,'thin','inf');
imshow(~K)
set(figure,'position',[1 1 600 600]);

%Minutae Extraction

fun=@(x)median(x(:));
L = nlfilter(K,[3 3],fun);
imshow(L)
LTerm=(L==1);
imshow(LTerm)
LTermLab=bwlabel(LTerm);
propTerm=regionprops(LTermLab,'Centroid');
CentroidTerm=round(cat(1,propTerm(:).Centroid));
imshow(~K)
set(gcf,'position',[1 1 600 600]);
%set(figure,'position',[1 1 600 600]);
hold on
plot(CentroidTerm(:,1),CentroidTerm(:,2),'ro')
LBif=(L==1);
LBifLab=bwlabel(LBif);
propBif=regionprops(LBifLab,'Centroid','I');
CentroidBif=round(cat(1,propBif(:).Centroid));
plot(CentroidBif(:,1),CentroidBif(:,2),'go')
```

CHAPTER 6

SIMULATED RESULTS:

Fig 6.1 Fingerprint Sample

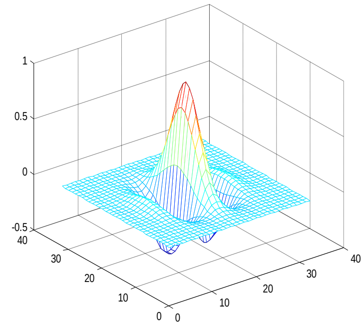


Fig 6.2 Gabor filter graph

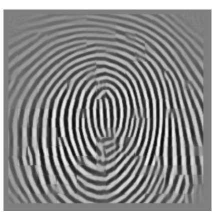


Fig 6.3 Enhanced Image

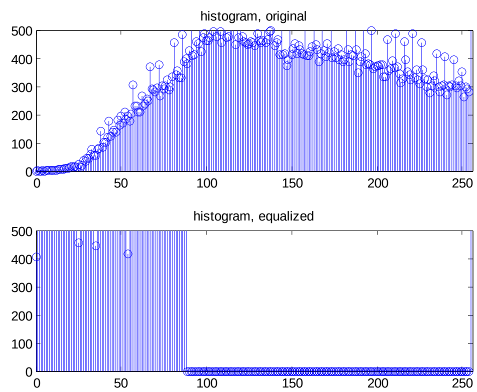


Fig 6.4 Histogram equalization

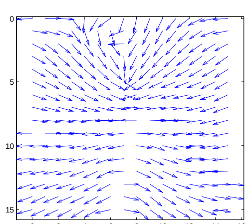


Fig 6.5 Field orientation

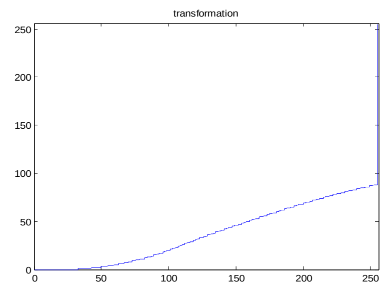


Fig 6.6

Fig 6.7 Image before and after histogram equalization

Fig 6.8 Fingerprint Sample

Fig 6.9 After Segmentation

Fig 6.10

Fig 6.11 Thinned image

Fig 6.12 Minutiae features extracted

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