FINGERPRINT IMAGE ENHANCEMENT AND RECOGNITION

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FINGERPRINT IMAGE ENHANCEMENT AND RECOGNITION

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This dissertation is submitted to Faculty of Engineering and Technology, International Islamic University Islamabad Pakistan for partial fulfillment of the degree of **MS Electronic Engineering** With specialization in **Communication and Signal Processing** at the Department of Electronic Engineering

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بسم الله الرحمن الرحيم

In the name of Allah (SWT) the most beneficent and the most merciful

DEDICATED TO MY SUPERVISOR, PARENTS AND EVERY ONE WHO PRAYED FOR MY SUCCESS

CERTIFICATE OF APPROVAL

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DECLARATION

I certify that research work titled "Fingerprint Image Enhancement and Recognition" is my own work and has not been presented elsewhere for assessment. Moreover, the material taken from other sources has also been acknowledged properly.

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ABSTRACT

This thesis is concerned with finding a novel and enhanced technique for fingerprint image enhancement The process is mainly divided into image preprocessing, features extraction and feature match For each task involved in the whole process recent methods with some classical techniques in literatures are analyzed For improved performance of the system, some new codes are proposed in the program code with novel solutions for enhancement such as canny edge detector and Difference of Gaussian are used

Some of the methods already used for enhancement, used different enhancement techniques, different images, and show good result in enhancing the images and also give more number of accurate minutiae and less false detection yet there is no one or accurate method that can be reliable and trusted for every application of fingerprint Keeping in mind the shortcomings of the existing methods used for enhancement Experiments are conducted to show performance enhancements which are encouraging and better than the already existing techniques

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In the name of Allah, the Most Gracious and the Most Merciful All praise and glory goes to Almighty Allah (SubhanahuWaTa'ala) who gave me the courage and patience to carry out this research work Peace and blessings of Allah be upon His last Prophet Muhammad (Sallulah-o-Alaihihe-Wassalam) and all his Sahaba (Razi-Allah-o-Anhu) who devoted their lives for the prosperity and spread of Islam

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There is no way no words, to express my love and gratitude May Allah helps us in following the true spirit & principles of Islam written down in the Holy Quran and Sunnah (Aameen)

Waqar Ahmad

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Introduction

In the world of computer security biometrics refers to authentication techniques that depend on measurable physical & behavioral characteristics that can be automatically checked [1] In other words, everyone has personnel attributes that can be used for distinctive identification purposes, including fingerprint, the pattern of retina voice characteristics etc as illustrated in figure 1 1 Fingerprint being the oldest and easily available trait of biometrics, offers a foolproof means of personal identification The science of fingerprint ID stands out amongst all other forensic sciences for many reasons and which let the first forensic professional organization the IAI (International Association of Identification) to launch in 1915 Biometric is a technique for distinctively recognizing individuals which is based on one or more natural physiological or behavioral property of the person The method is much accepted as compared to the traditional token - based or knowledge – based method involving ID - cards PIN numbers, SSN etc The reasons behind acceptance of biometric for personal identification/authentication are

- The physical attendance of the person is required to get itself Identified/authenticated
- The particular identity cannot be stolen, lost forgotten shared or hacked[2]

1.1 Biometric Identification and Fingerprint

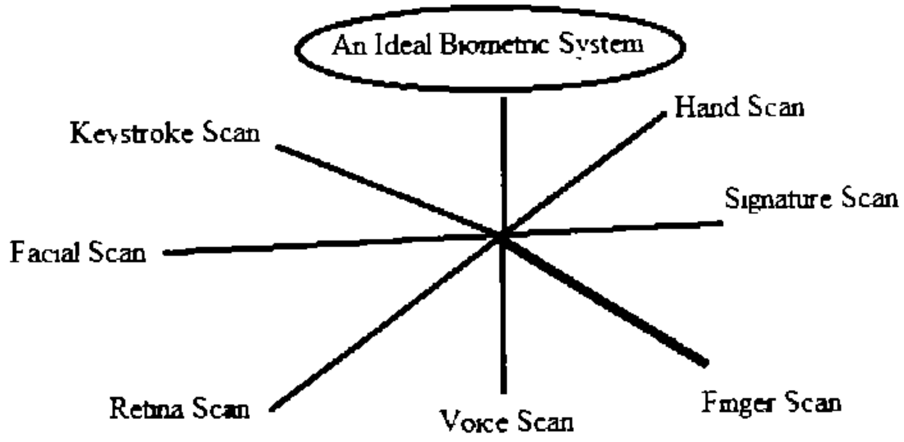


Figure 1.1 An Ideal Biometric System [3]

Among the available physiological biometric traits some of the traits outperform others[4] Humans have used fingerprints for personal identification since many decades The matching accuracy using fingerprints has been shown to be very high as compared to other existing biometric traits [5] Unlike face and voice patterns fingerprints are persistent with age and cannot be easily disguised [6]

It is thought that the first known instance of biometrics in practice was a form of fingerprinting being used in the 14^{th} century in China as stated by explorer Joao de Barros [7] In 1880, Dr Henry Faulds [8] published an article, 'Nautre' and discussed fingerprints as a means of identification, the use of printers ink as a way for attaining such fingerprints In 1882 Bertillon [8] for the first time devised a system of classification known as Anthropometry, which measures the parts of the body as the primary means of identification for judicial identity He later introduced and included fingerprints for the judicial identification

Fingerprints are incomparably the most sure and unchanging form of all other forms of signature [9] A fingerprint is constituted by a set of ridge lines which often run side by side, sometimes intersect and terminates sometimes The points where the ridge lines terminate or fork are called the minutiae [10] Whereas according to Galton each ridge is characterized by numerous minute peculiarities called minutiae which may divide and almost immediately reunify, surrounding a small circular or elliptical space or sometimes the independent ending or beginning of ridges Lastly the ridge pattern of the fingerprint image may be so short so as to form a small island even

Later Edward Henry (1850 - 1931) [11] refined Galton's classification by increasing the number of classes of fingerprint images Maximum amount of all the classification schemes presently used by the police agencies are variants of Henry's classification scheme The scheme adopted by FBI defines three major classes and eight sub classes as shown in Figure 1 2

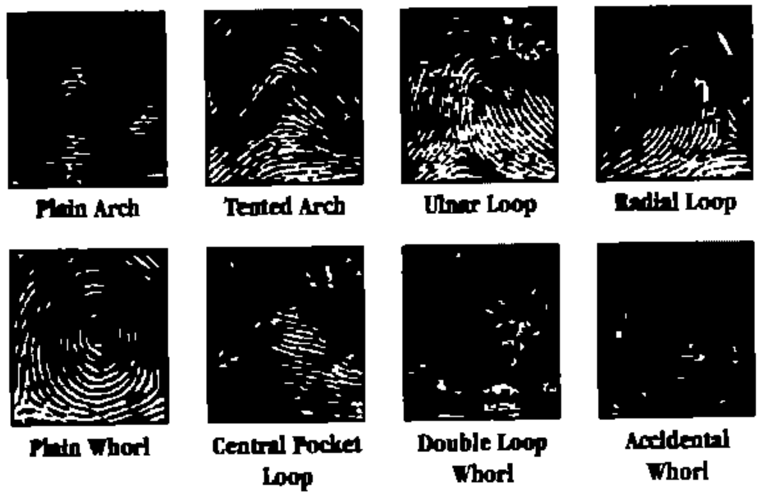


Figure 1 2 Henry's classification of fingerprint Patterns

The three major classes are

a) loop
b) arch
c) Whorl

a) Loop Patterns

In a Loop pattern, the ridges will flow in one side , recurve , pass through or touch an imaginary line drawn from the core to the delta, and leaving the pattern on the same side from which it entered A loop pattern has only one delta The delta is found as a triangular area where the ridge radiates outward in three directions

Loop patterns has two types

1 Ulnar loop

2 Radial loop

b) Arch Patterns

In an arch pattern . ridges starts in one side and run out the opposite side Arch patterns has no deltas and are of two types

1 Plain arch

2 Tented arch

c) Whorl Patterns

A whorl pattern consists of a series of almost concentric circles whorl pattern has four types

1 Plain whorl

2 Central Pocket Loop whorl

3 Double Loop whorl

4 Accidental whorl

Whorl patterns account for 25% of fingerprints [12]

A fingerprint is the pattern of interleaved valleys and ridges on the surface of a fingertip whose formation is determined during the first seven months of fetal development It has been empirically determined that the fingerprints of identical twins are different and so are the prints of each finger of the same person [5]

A genetic code in DNA gives general instructions on the way skin should form in a developing fetus, but the specific way it forms is a result of random events (i e the exact position of the fetus in the womb at a particular moment and the exact composition and density of surrounding amniotic fluid) This is the reason behind the difference in fingerprint even in identical twins case [13] The fingerprints are fully stable at about seven months of fetus development and finger ridge configuration does not change throughout the life of an individual , except in case of accidents such as cuts on the fingerprint etc [14] Sir Francis Galton conducted an extensive study on fingerprints and introduced the minutiae features for fingerprint matching in 1888 [8] The two most noticeable ridge features called minutia points, are ridge bifurcations and ridge endings [15] Figure 1 3 illustrates the example of fingerprint with its ridge bifurcation and ridge ending patterns In a fingerprint image valleys are bright whereas ridges are dark Ridges and valleys often run in parallel sometimes they bifurcate and sometimes they terminate The figure 1 4 shows some examples of valleys and ridges

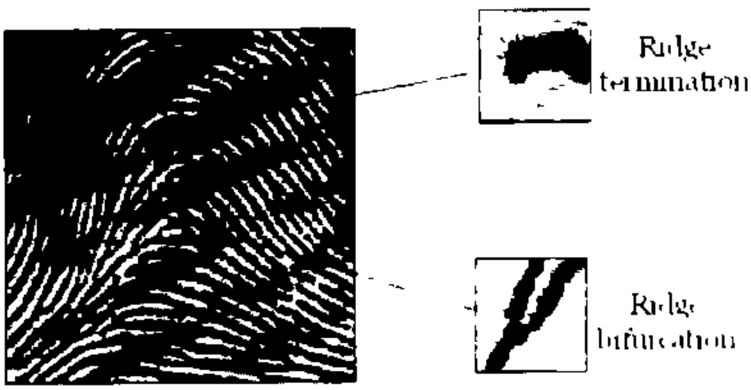


Figure 1 3Close-up of ridge termination and ridge bifurcation

Figure 1.4 Depiction of ridges and valleys

A minutia based fingerprint identification system approaches towards extraction of the ridge patterns correctly. A good quality fingerprint contains 25-80 numbers of minutiae [16] depending on the sensor resolution and finger placement on the sensor. However the latent fingerprints or the fingerprint images taken through poor scanners, are found to have fewer amount of minutiae points. In order to safeguard the minutiae extraction procedure to be a healthy one, the system must have good quality of fingerprint images as input and this gives a reason to the fingerprint images for enhancement.

1.2 Problem Statement:

The fingerprint images are hardly of ideal quality, due to the reasons like variations in impression condition , skin condition, scanning devices or may be due to non-cooperative approach of the subject. This corrupted quality of image can result in a major number of spurious minutiae being formed and genuine minutiae being ignored. A key step in studying the statistics of fingerprint minutiae is to reliably extract the minutiae feature from fingerprint images. Thus it is vital to employ image enhancement techniques prior to minutiae extraction to get a good number of reliable estimate of minutiae locations[18]

Many tactics have been taken to improve the fingerprint images at various steps of enhancement which includes, normalization, extraction of region of interest, ridge orientation estimation, ridge frequency estimation, morphological steps involved detection and matching etc

Some of the methods already used for enhancement, used different enhancement techniques, different images, and show good result in enhancing the images and also give more number of accurate minutiae and less false detection, yet there is no single or accurate method that can be reliable and trusted for every application of fingerprint Keeping in mind the shortcomings of the existing methods used for enhancement, in this thesis a novel method of improving the quality of the fingerprint image and obtaining better result is experimentally discussed and simulation details are given

1.3 Objective

The core objective of fingerprint image enhancement is to recover the ridge characteristics of the image, as these ridges carry the information of characteristics features necessary for minutiae extraction Ideally in a well-defined fingerprint image, the ridges and valleys should alternate and flow in a locally constant direction This regularities facilitates the detection of ridges and consequently allow minutiae to be precisely extracted from the thinned ridges [17] Thus, the corruption or noise has to be reduced through image enhancement techniques to get enhanced definition of ridges against valleys in the fingerprint images

1.4 Contribution

New contributions in this thesis are

1) The introduction of candy edge detector in the enhancement process
2) Experiments shows the proposed algorithm is better
3) The Code used is easily adapted
4) The Code is easily implemented

1.5 Thesis organization

Rest of the thesis presents a better performance to minutiae based fingerprint image enhancement Chapter 2 provides the literature review. Chapter 3 presents the methodology and implementation of a series of techniques on fingerprint image for enhancement and chapter 4 Provides discussions on minutiae extraction technique and chapter 5 provides experimental results and comments while conclusion and future extensions which can be made to this project are in chapter 6

Chapter 2

Literature Review

Numerous researchers have added to the area of fingerprint image enhancement As in the previous section the need of enhancement is been discussed, still these identification system is popular because of its inherent ease in image acquisition the numerous sources been available for collection of data to create a strong database of fingerprint images and their established use and collection by law enforcement for personal identification and verification of the subject

Usage of fingerprints in recognizing characters has been in use since 19^{th} century when Francis Galton defined some of the features from which fingerprints can be used for identification These "Galton points" are the basis for the science of fingerprint identification, which has extended and improved over time Fingerprint identification began its transition to automation in the late 1960s along with rise of computing technologies With the arrival of computers, a subset of Galton points, denoted as minutiae, has been used to develop automated fingerprint technology

In the year 1998 Lin Hong et al [15] have proposed a fast fingerprint enhancement algorithm The algorithm improves the ridge valley structure based on estimated local ridge frequency and orientation Goodness index value for the minutiae verification and calculation is used for the performance of image enhancement algorithm The disadvantage with the suggested technique is that it flops in case of noisy images In the year 2000 Greenberg et al [19] proposed two approaches for fingerprint enhancement The first scheme is carried out with local histogram equalization, image binarization and Wiener filtering The second scheme use an unique anisotropic filter for direct gray scale enhancement The results of the method performed improved for enhancement and the average error percentage in terms of false and dropped minutiae produced. by the suggested approach are significantly lower The improved Gabor filter approach(that has considered the novel factors for standard deviation) works better for poor quality images with degraded ridges and blocks

In the year 2002 Yuliang He et al [20] offered a different technique for orientation estimation to the fingerprint image where the ridge orientation direction of a pixel is divided in eight directions The ridge direction of each pixel value of those eight directions, have been applied with 9 * 9 window with the pixel at the center During the binarization stage, direct binarization of the image with its orientation field is applied in place of binarization by means of global thresholding

In 2003 R Thai [17] in his thesis work showed three additional stages added to the already existing enhancement methodology of Hong et al [15] The stages are segmentation of the image binarization and thinning of the image During segmentation he used a method based on variance thresholding to separate the foreground region of the image from the background regions The binarization is done considering the global threshold value and the thinning process is performed using 2 iterations via MATLAB operation thin' and the MATLAB function bwmorph' Minutiae extraction is done by crossing number method D Maltoni et al [21]in the same year have proposed a mean and standard deviation of the fingerprint image to extract region of interest which has the advantage of ease in calculation The disadvantage is that it does not cut edges very well and even does not work well on too dry or too wet fingers

In the year 2004 Sen Wang and Yangsheng Wang [22] approached for bandpass filters to remove the undesired noise in the fingerprint images It has the disadvantage that it concentrates only on the singular point of the image In the same year Chaohong Wu et al [23] have applied an combination of anisotropic filter and directional median filter(DMF) to enhance the fingerprint images as Gaussian-distributed noise are reduced efficiently by anisotropic filters and impulsive noise are reduced by DMF The suggested system has advantages like. features of ridge boundaries became further smooth ridges that are broken are joined perfectly, the holes in the ridges are completely removed The disadvantages with the approach are like pores of fingerprint ridges are completely removed which originally lied in input fingerprint image, the anisotropic filter parameters and the window length are set empirically and exhibits failure when applied on heavily noisy images and orientation calculation also fails for those regions on fingerprint

In the year 2006 S Chikkerur et al [24] introduced a novel approach for fingerprint enhancement based on STFT (short time Fourier transform) analysis and the result of the method is dependent on the choice of the window(i e a 12£12 window) for resolving the properties of the images both in frequency and space Through enhancement in the first phase the author has used a raised cosine window that outlines the image and is responsible for computing all the intrinsic images (i e the images those represent the vital properties of the fingerprint image as a pixel map of fingerprint) and in the second stage the image is distributed in overlapping windows and a band-pass Butterworth filter is used on every window to rebuild the enhanced image by tiling the results of enhancement of every single local window A relative improvement of 17% in the fingerprint recognition rate is observed after enhancement

In the year 2007 Xi-Feng Tong et al [25] proposed a two level convolution

template which is designed according to ridge direction and a simplified convolutionis used to enhance fingerprint image The proposed algorithm is faster consideringthe time difficulty factor and shows better results than the Gabor filter based enhancement In the same year S A Sudiro et al [26] proposed

an approach for fingerprint images to detect minutiae which considers valleys insteadof ridges and the approach is based on crossing number procedure This algorithmtakes relatively lesser time for calculation and the number of minutiae points are closer to the actual number of minutiae existing in the fingerprint image The shortcoming lying with the method is that it has a rather poor thinning process

In 2008M Sepasian et al [27] proposed a (CLAHE) contrast limited adaptive histogram equalization method for histogram equalization based enhancement on the fingerprint images They have also approached for an adaptive binarization method Previously in binarization an unique threshold value is set locally for general fingerprint image analysis but they vary in terms of contrast and intensity According to the proposed technique thinning is done by using an initial slide neighborhood process to eliminate the growth of incorrect information in fingerprint image and the resulting image is produced only in one step, without any intermediate filtering and consequently with less computational complexity In the year 2009 Ibrahim et al [28] have proposed a directional Gaussian filter for smoothing Directional exploration is performed by the Non-Subsampled Contour-let Transform(NSCT) on the smoothed image and then directional energies are used for the reconstruction of enhanced image Basically the NSCT, is based on the concept of Non-Subsampled Laplacian Pyramid and Decimation-Free Directional Filter Banks (DDFB) also known as Non-Subsampled Directional Filter Banks

A use of Non-Subsampled Laplacian Pyramid is carried out to decompose the image into high-pass and low-pass After that the Non-Subsampled Directional Filter Bank is applied only to the high-pass images to further decompose the frequency band This enhanced image is the result of addition of the resultant images from three stages of NSCT and a maximum energy on every pixel of the image is calculated

In the year 2010 Mao et al [29] proposed a convenient way for fingerprint ridge orientation calculation Along with that a modified Gabor filter based filtering is applied to compute ridge orientation and ridge frequency Here the Gabor filter needs to compute a quarter of the original filtering calculation Henceforth the fingerprint enhancement technique guarantees on lesser time consumption (i e in seconds) and expenses too In 2011 Shila Samantary propose a DOG (Difference of Gaussian) based Fingerprint Image Enhancement technique In this approach Gaussian filter with Different Parameters is applied to the input image and the difference image of the two Gaussians is used for feature extraction [33]

Chapter 3

Methodology

3.1 Segmentation

The first task is to find the region of the fingerprint from the image In this task morphological operations have been used First the image is threshold and inversed to produce a white fingerprint on a black background Then, the binary image is dilated and the holes are filled inside a for loop until the image contained only one connected component After this, the image is eroded as many times as it is dilated to compensate the expansion of the borders The result is a mask for the fingerprint region The original fingerprint image and a mask generated using this algorithm are seen in Figure 3 1

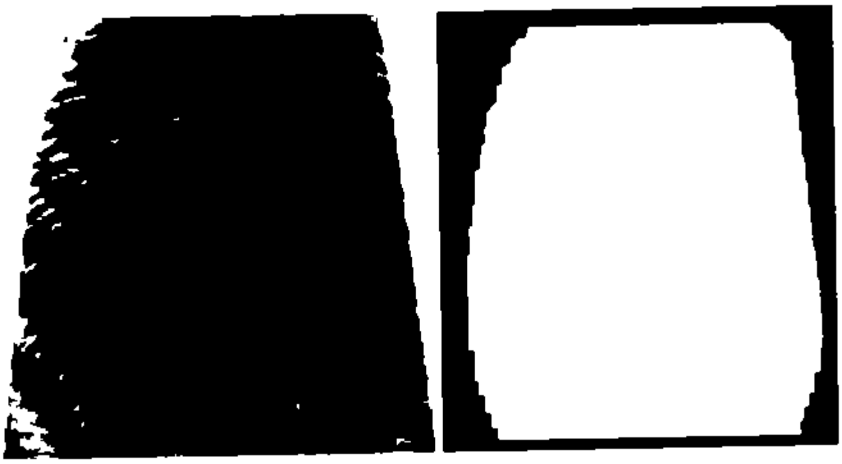


Figure 3 1 Segmentation
Left) Original Image Right) Segmented Mask of Left

3.2 Canny Edge Detector:

In this approach canny edge detector is used to sharpen the ridges in the fingerprint image The Sharpening is done in such that the edges of the ridges are found out and when the edges are found the distance between the ridges is a little widened as the black pixels are thinned Canny operator s constraints let it to be personalized to recognition of edges of differing characteristics depending on the particular necessities of a given application The Canny algorithm contains a number of adaptable factors, which can affect the time of computation and efficiency of the algorithm

3.3 Contrast Enhancement:

For contrast enhancement (CE), adaptive histogram equalization is used Adaptive histogram equalization enhances the contrast of images by altering the values in the intensity image, working on small data regions (tiles), rather than the whole image The neighboring tiles are then combined using bilinear interpolation in order to remove artificially induced borders The difference, especially in homogeneous zones, can be limited in order to dodge amplifying the noise which might be existent in the image

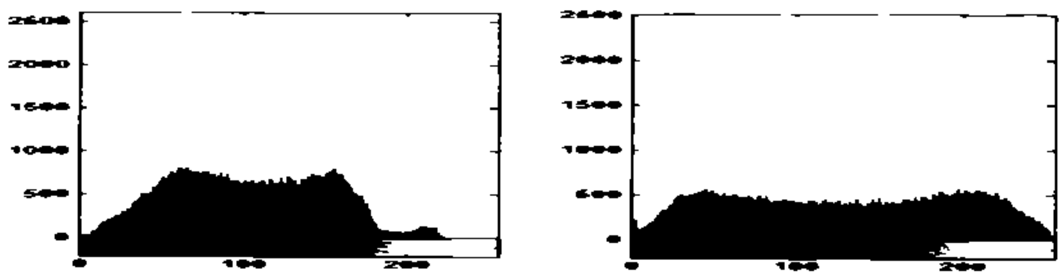


Figure 3 2 Contrast Enhancement
Histogram of the Image before(left) and after(right) contrast enhancement

3.4 Normalization

In the second task, the original image is normalized to yield an image with the desired mean value and variation This is done using the formula

$$N(i,j) = \begin{cases} M_0 + \sqrt{\frac{V_0(I(i,j)-M)^2}{V}}, I(i,j) > M \\ M_0 - \sqrt{\frac{V_0(I(i,j)-M)^2}{V}}, \ else \end{cases} \quad (3\ 1)$$

Where N is normalized image, I is the input image,

M_0 and V_0 are the desired mean value and variation, M and V are the original ones

As it can be the contrast in the normalized image is much better than in the original

Figure 3 3 Normalization
Before (Left) and After (Right) Normalization

3.5 Generation of the Ridge Orientation Image

Next, the orientation of the ridges was detected by using Sobel masks The image was filtered blockwise In each block, the horizontal and vertical edge responses to the Sobel gradient operations were calculated using the edge function of Matlab The orientation of the ridges inside the block was calculated using the equation

$$\theta_{x,y} = 0\,5 \tan^{-1}\frac{G_{yy}}{G_{xx}} \quad (3\ 2)$$

The next step is to calculate the ridge frequencies in the blocks the orientation is calculated A window with the size L x W was placed at each block so that its center point was at the center point of the block and its orientation was the same as the calculated orientation of ridges in the block This is seen in Figure 3 5 The window size for the frequency calculation was 62 x 31

This is reasonable, since the oriented window should be about twice as wide as high (in the original paper [1], size 16 x 16 was used in the orientation calculation and 32 x 16 in the frequency calculation) to contain several ridges to calculate the frequency of Also this is illustrated in Figure 5 The ready frequency image as well as the normalized fingerprint image is seen in Figure 6

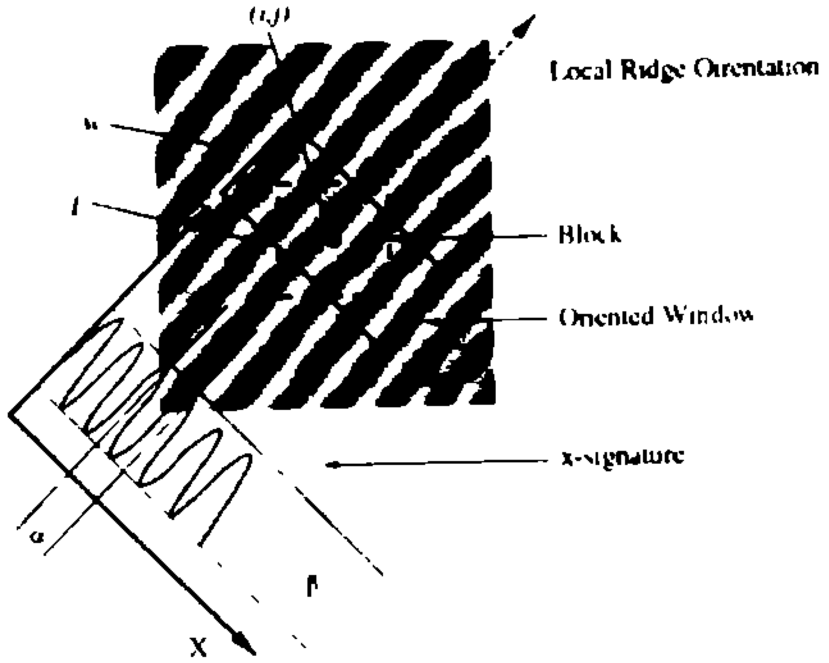


Figure 3 5 Illustration of Orientation window [3]

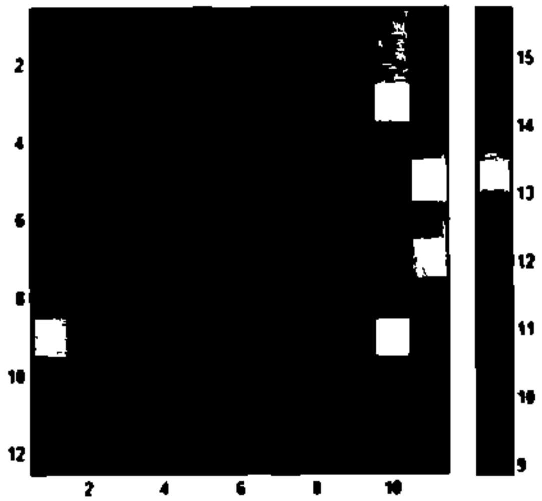


Figure 3 6 Ridge Frequency Image

As shown, the frequencies are higher in the edge regions and near the center This is because the changes in the orientations are higher there as there are more ridges in the edges than in center

In later steps it was noticed that the result of Gabor-filtering and the binary image was smooth but the filtering did not fuse ridges with this value Especially in the lower section of the fingerprint, there are lots of broken ridges because of a possible cut in the finger These ridges can be restored in later phases The frequency image is also smoothed The smoothing is done in 3 x 3 blocks and that is why the frequency image has to be zero-padded before smoothing After the zero-padding, over-indexing cannot happen

3.7 Gabor Filtering:

After knowing the ridge orientation and frequency in each block, it is possible to filter the image blockwise with the Gabor filter The Gabor filter for each block is defined as

$$h(x, y: \varphi, f) = e^{\left\{-0.5\left[\frac{x_\varphi^2}{\delta_x^2}+\frac{y_\varphi^2}{\delta_y^2}\right]\right\}\cos(2\pi f x\varphi)} \quad 3.4$$

$$x_\varphi = x\cos\varphi + y\sin\varphi \quad 3.4a$$

$$y_\varphi = -x\sin\varphi + y\sin\varphi 3.4b$$

Where φ is the orientation of the Gabor filter (perpendicular to the ridge orientation) f is the frequency of the block, and δ_x and δ_y are the standard deviations to the directions of x and y axes, respectively, and (x y) is a 2D coordinate grid for the Gabor filter

The filtering was done with the blockproc command in Matlab Block size was the same the orientation and frequency was calculated in, 31 x 31 To get a smoother filtering result where the borders of the blocks would not be visible, a border of 21 pixels was used for the blocks

Figure 3 7 Gabor Filtering
Normalized Image (Left) and result of Gabor Filter (Right)

For each block, the appropriate 21 x 21 Gabor filter was generated with Equation 4 The size 21 x 21 for 31 x 31 blocks is comparable with the 11 x 11 filter size for 16 x 16 blocks used in the original paper [3] The value used for δ_x and δ_y was 0 5 x f

It is convenient that the values for the standard deviations are adaptive to the ridge frequency in the processed block Also, the experiments done showed that these values works well After defining the Gabor filter for the block, the block was filtered using the "imfilter command The values outside the mask as well as the NaN values were set to zero After Gabor filtering, it is easy to generate a binary image by threshold of 0 Figure 6 presents the normalized fingerprint image, the filtered image and the binary image generated from the filtered image In the binary image, the ridges are set to the value 1 and background to the value 0

3.8 Thinning and Minutiae Extraction

The binary image yielded in the previous step was thinned by using the bwmorph command of Matlab From the thinned image, the bifurcations and endings are easy to find However there are always undesired spurs in the thinned image caused by the unevenness of the binary image as seen on the left of Figure 3 8

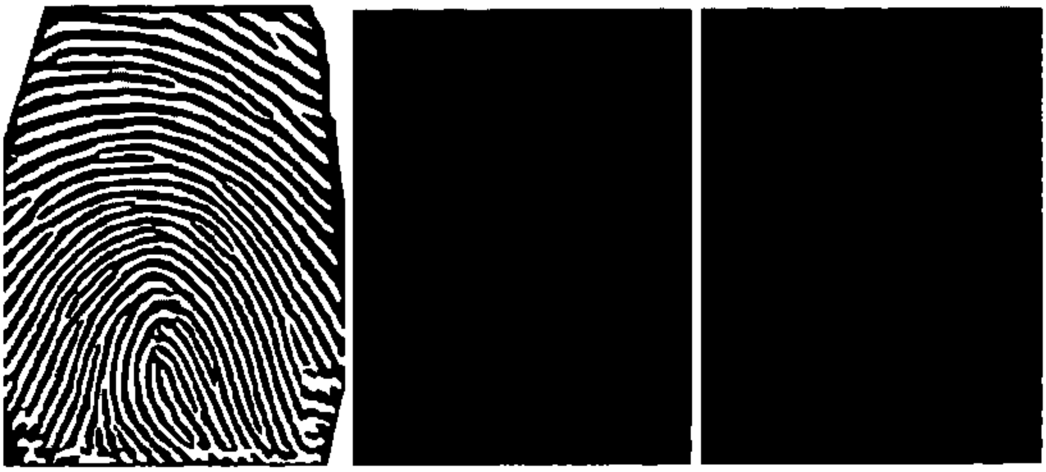


Figure 3.8 Displaying Minutiae
Binary Image (Left), Thinned Image (Center) and Image showing Minutiae (Right)

These spurs have first to be deleted. The removal of the spurs i.e. pruning was done as follows

1. The current skeleton image skel is saved to the image old_skel

2. The end points and branch points of skel are detected using the bwmorph command

3. The 3 x 3 neighborhoods of the branch points in the skeleton image are set to zero

The result is saved to the image spurs

4. All the connected components that do not contain an end point detected in phase 2

are removed from the image spurs. In this step, the command 'bwselect' is used

5 The connected components containing more pixels than a parameter max_length (here, 10) are removed from the image spurs

6 The image spurs is subtracted from the image skel

7 The end points in skel are detected using the bwmorph command

8 All end points of skel in 3 x 3 neighbourhoods of the branch points detected in phase 2 are set to 0

9 The phases 1 – 8 are repeated until there is no difference between skel and old_skel

The last phase ensures that also spurs with spurs are removed A close-up of the skeleton image before and after pruning is seen in Figure 3.9

Figure 3.9 Removing Spurs
Image before (Left) and After Removing Spurs (Right)

After removing the spurs, the bifurcations and the endings of the ridges were detected by utilizing the crossing number Crossing number is defined as

$$CN = 0.5 \sum |P_i - P_{i+1}|, P_9 = P_1 \qquad 3.5$$

Where P1 is the pixel on the right side of the pixel the crossing number is defined for and P2 is the next pixel in CCW direction. The crossing number is calculated for each white pixel of the skeleton. The pixel is an ending if CN = 1 and a bifurcation if CN = 3. The row and column of the bifurcations and endings are saved. Figure 3.10 shows the bifurcations and endings plotted on the pruned skeleton image.

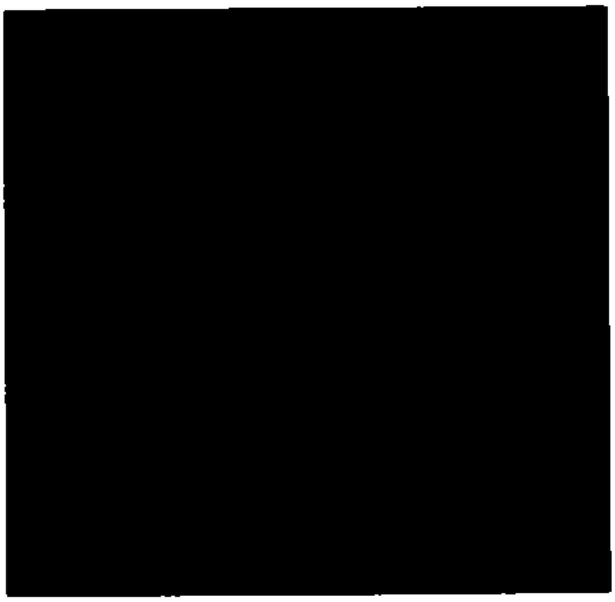


Figure 3.10 Skeleton (Thinned Image) showing Bifurcations (Blue) and Endings (Red)

The outermost endings in Figure 3.10 should not be used for matching since they are dependent on the pose fingertip when the fingerprint has been taken. Thus, the ending points that are too close of the borders of the mask should be discarded.

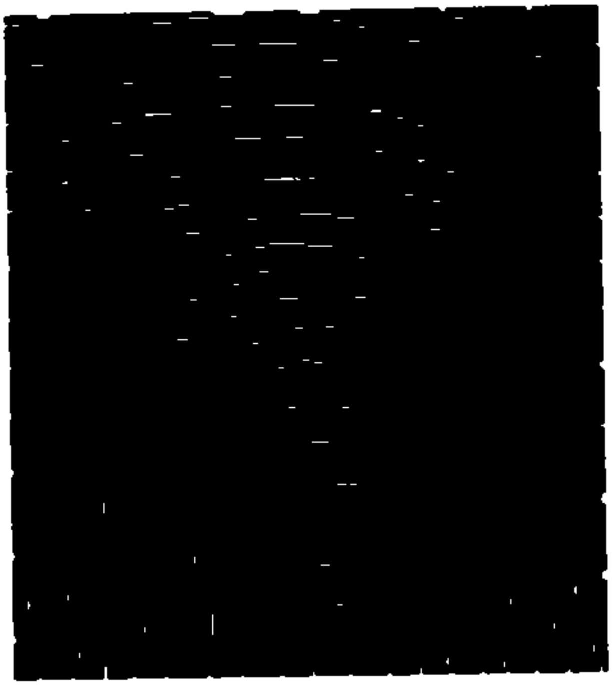


Figure 3 11 A Zoomed Section of figure 3 10 image with cleaned

endings is shown in Figure 3 12

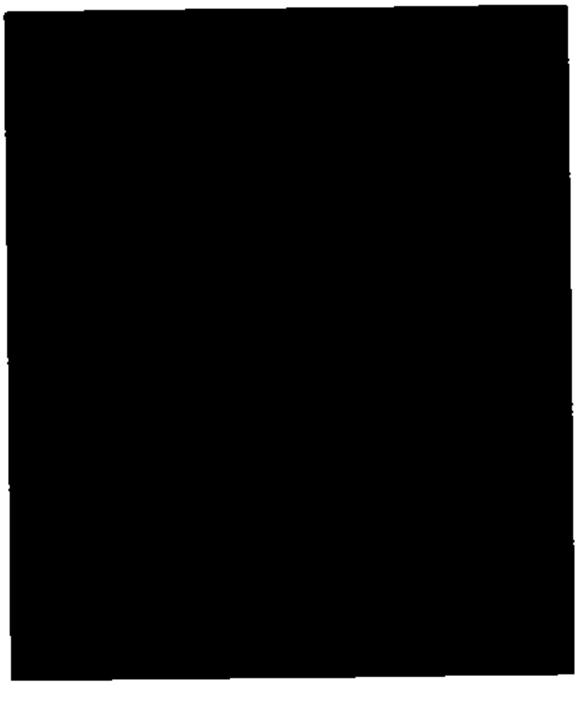


Figure 3 12 Cleaned Image

The fingerprint Cleaning is done by first removing the inner parts of the mask, dilating the edge 5 times & removing the end points afterwards, which lay on the dilated edge. This means that the end points with distance of 5 pixels or less to the edge are removed

Chapter 4

Recognition

The most important part is of a fingerprint recognition system is fingerprint matching method [31]. When the thinned image is obtained which is cleaned from all spurs the minutiae matching is relatively easy. As there is a defined coordinates of each minutiae point especially with reference to the core point, which is also obtained in some experiments

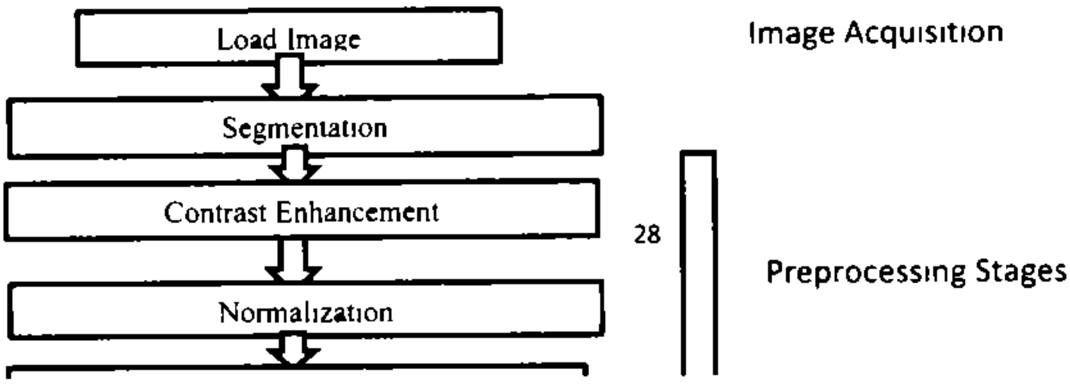


Figure 4.1 Flow chart of Fingerprint Image Enhancement and Recognition

4.1 Minutiae Matching

Because the position of the fingertip can vary between the imaging of the fingerprint there will be some rotation & translation between the extracted features. Also, the scale can change subject to the device taking the images and there might appear some cuts. Also, the fingertip is a 3D structure whereas the fingerprint is 2D therefore, non-linear transformation can also occur between the images [31]

After extracting the set of (features) i-e minutia points of two fingertips images to be tested, minutiae matching is performed to check whether they belong to the same person or not

An alignment based match algorithm is used. It includes two stages: first is the alignment stage and then the matching stage

1. Alignment Given two sets of fingerprint images to be matched, choose any one minutia from each image, calculate the similarity of the two ridges associated with the two referenced minutia points using the similarity equation

$$Sim = \sum^{m}_{i=0} z_i Z_i / [\sum^{m}_{i=0} z_i^2 Z_i^2]^{(1/2)}$$

where $(z_1 - z_n)$ & $(Z_1 - Z_N)$ are the set of minutia for each fingerprint image respectively And m is minimal one of the n and N value It the similarity score is larger than 0.8, then go to step 2, otherwise continue to match the next pair of ridges

Where the series of z-coordinates $(z_1, z_2 \ldots z_n)$ of the points on the ridge represents the ridges For each ridge length L a point is sampled starting from the minutia point, where the L is the average inter-ridge length And n is set to 10 unless the total ridge length is less than 10*L

For similarity larger than a fixed point (the threshold) each set of minutia is transformed to a new system (co-ordinates) whose origin is at the referenced point & whose z-axis is coincident with the direction of the referenced point

2. Matching stage When two sets of transformed minutiae points are obtained the adaptable matching algorithm is used to calculate the matched pairs of features (minutiae) by supposing (based on a pre-defined threshold) that the two minutia having almost the same position and direction are duplicate (of the same person)

Using the following formula the minutiae points are translated and rotated

$$\begin{pmatrix} yi\_new \\ zi\_new \\ \theta i\_new \end{pmatrix} = TM * \begin{pmatrix} yi - y \\ zi - z \\ \theta i - \theta \end{pmatrix} \qquad 4\ 1$$

where (y,z,θ) is the parameters of the reference minutia and TM is

$$TM = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad 4\ 2$$

The following diagram illustrate the effect of translation and rotation

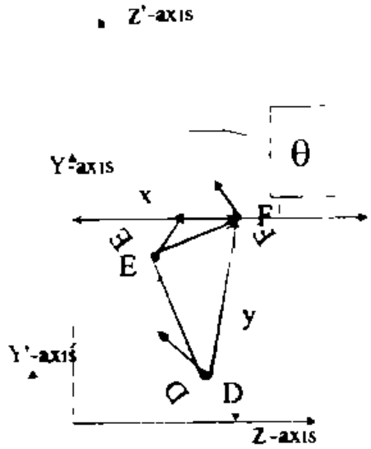


Figure 4 2 Axes translation and orientation

The newly obtained coordinate system is created at minutia F and the new z-axis is coincident with the direction of minutia F

In Matlab a bounding box around each template minutia is placed If the minutia to be matched is within the box & the difference between them is within a specific threshold (which is very small), then the two minutiae are regarded as a matched minutia pair Here we assume that the scales are not changed since the images are taken by the same device

Figure 4 3 Minutiae Matching

Chapter 5

Experiments and Discussion

This chapter will give detail of the experiments conducted in this research work and performance analysis has been given Images are taken from a database which is already extensively used for experiments on fingerprint image enhancement and recognition For the purpose of simulation and experimentation, more than hundred images are selected from the big database of Fingerprint Verification Competition (FVC 2004) DB2, which is available online for free The purpose of choosing this database is obviously because it's freely available and is used extensively by scientists and students for their research purpose in the fingerprint area of study and every couple of years a competition is held internationally based on the databases of FVC In this research work the main features which are used for recognition and enhancement are the minutiae The minutiae extracted are analyzed for different characters such as the distance between the minutiae, the core points and the standard deviation

The sequential steps and the results are as follow

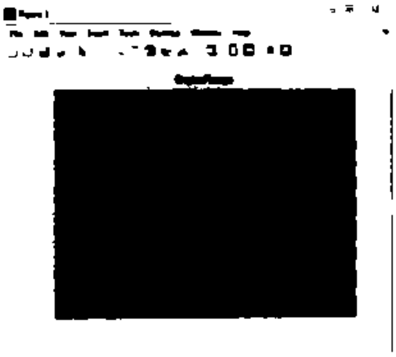
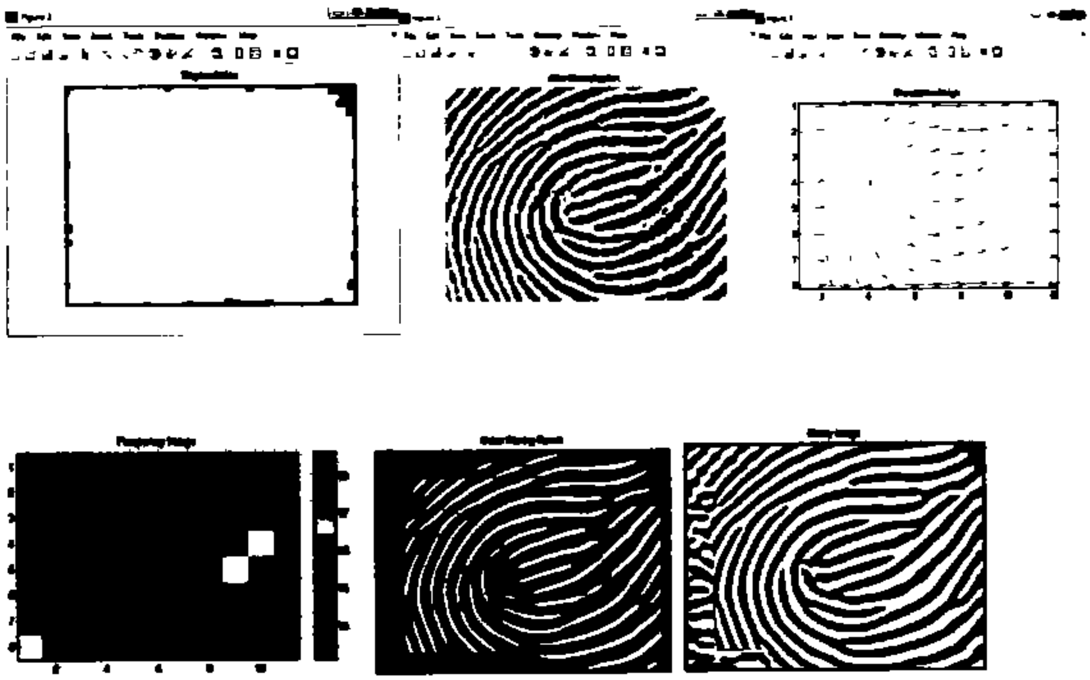
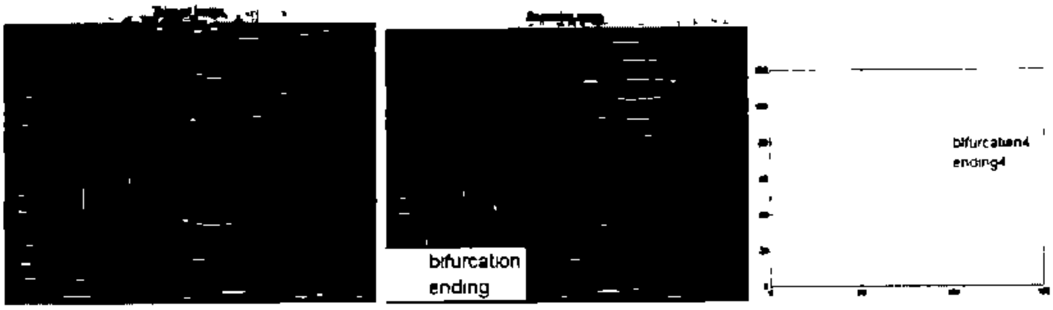


Fig 5 1 Original image





First of all a program code is built in MATLAB for all the tasks in this thesis The original images segmentation mask is found, then it is normalized After normalization the orientation image and the frequency estimation is found Then these results are fed into a Gabor filter to get enhanced image The enhanced image is then binarized then and then minutae points are extracted As in all biometric systems even a small change in the input parameters and factors result in a fine deviation in the result As there are more than seven different stages involved in the whole process and the output of one stage is fed into another stage with every stage having different independent parameters of its own Therefore the final results may vary even in a slightest change of parameter in any of the involving stages The experiments show that the program can differentiate spurious/false minutia pairs from genuine pairs of minutiae within a certain threshold If not for the brevity of time further accuracy in each stage and fine tuning by further image enhancement technique further improvement in the result is expected

Listed below is a diagram for the distribution of minutiae that are present in the original image and the distribution of minutiae that are in the image obtained after enhancement

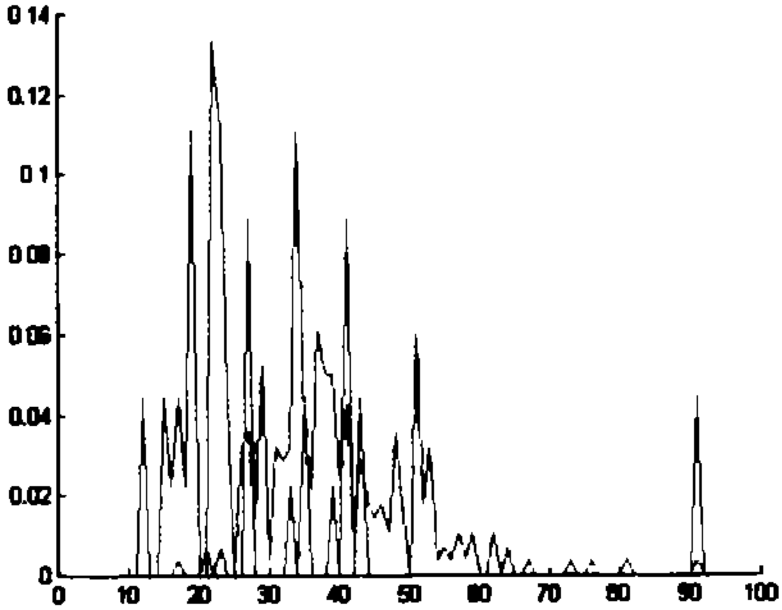


Figure 5 1 Distribution of genuine match and false match
Spurious minutiae score is represented by red lines and genuine by green line

Two distribution line which are partially overlapped can be seen in the figure 5 1

The Red line whose highest point is to the left implies that the mean of the false minutiae match is 25 And the green line whose highest points are mainly on the right side of red line and it speak is on 35 Which shows that this algorithm can get a fine result by changing the threshold to an appropriate value The number 25 false minutiae match means that this algorithm will accept 25% of incorrect images as being matched and 35% of correctly matched images will be termed as not-matched Further improvement is found by finding the minutiae distance and their standard deviation in the fingerprint images

Table 5 1 SUMMARY OF RESULTS FOR CALCULATING THE SHORTEST DISTANCE BETWEEN NEIGHBOURING MINUTIAE

Experiments by	Sample Size (images)	Minutiae distance (pixels)	Standard deviation (pixels)
1 Raymond Thai [32]	30	25	13
2 Current (proposed)	85	20	11

The sample size in Table 5 1 represents that the total number of distances calculated between a reference minutia point and its nearest neighboring minutia point For the current algorithm it can be seen that the standard deviation which is taken pixel-wise is lower than that obtained by that obtained from the algorithm used by R Thai 2003 The standard deviation also shows that the minutiae are not evenly distributed in the images of the sample size, which is a confirmation of the naturally occurring minutiae in a fingerprint

TABLE 5 2 COMPARISON OF THE PROPOSED ALGORITHM WITH UNENHANCED JAIN'S ALGORITHM, SHILA SAMANTARAY S AND PROPOSED ALGORITHM

Type of algorithm	Average no of Bifurcations	Average no of Endings	Average no of Total Minutiae
Unenhanced	86	96	192
Jain [3]	147	53	200
S Samantary [33]	104	43	147
Proposed	62	25	87

As earlier suggested by the famously used algorithm of Jain et al [3] that a good fingerprint image contain 60-80 number of minutiae points on average From the table 5 2 it can be seen that the proposed algorithm shows a better result

Chapter 6

Conclusion

The main objective of this thesis was to find an algorithm for a better image enhancement technique for fingerprint images Canny edge detector was used for this purpose Real images from the database FVC 2004 were used and a series of image enhancement techniques were applied to them Experimental results have shown that the algorithm was successful in getting good orientation estimation and frequency estimation of the minutiae data The result of the Gabor Filter was also of a fine quality though the bottom area of the images were adding a little noise to the images which was compensated by further segmenting this part out of the images As obviously this did effect the amount of minutiae points in the images but practically for the recognition/matching the top and middle parts of the images were enough to produce effective results This occurrence of noise can be further reduced by finding an appropriate window and block size for the parameters of Gabor filter, which can be done as a future work of this project Also for the future work it is suggested to devise an algorithm to automatically select this non-noisy part because it not only decrease the size of the images but also the minutiae data is decreased, which can be helpful in obtaining the same result but in a shorter time Overall the project shows a better performance comparing to some of the algorithm currently used and can be used in fingerprint applications The future work includes

1) Further study into the Gabor filter to enhance the image and get a better result in the region of interest Though the images are enhanced in the region of interest the occurrence of noise is still an issue
2) Looking into other image enhancing techniques which can also be implemented along side the Gabor filter
3) Full analysis of the result obtained by looking into other statistical data of the features obtained
4) Using a bigger database to have a larger sample size to get more diverse images

References:

[1] Maltoni D , Maio, D Jain A K and Parbhakar, S

Handbook of fingerprint recognition Springer New York 2009

[2] Lee, H C and Gaensslen, R E Advances in fingerprint technology Elsevier, New York 1991

[3] Hong, L , Wan, Y F and Jain, A Fingerprint image enhancement Algorithm and performance evaluation IEEE Transaction on Pattern Anal, 20, 8 (1998) 777- 789

[4] Greenberg, S , Aladjem, M , Kogan, D and Dimitrov, I

Fingerprint image enhancement using filtering techniques

15th International conference on pattern recognition,(2000), 322-325

[5] Jang, W , Park, D , Lee D and Kim, S J Fingerprint image enhancement based on a half Gabor filter Advances in Biometrics, Proceedings, (2006), 258- 264

[6] Lee, C E and Bhattacharjee, N Fingerprint Image Processing and Minutiae Extraction for Fuzzy Vault In proceedings of the 7th International Conference on Advances in Mobile Computing & Multimedia (Kuala Lumpur Malaysia 2009) Emerald

[7] Wang W Li J W , Huang, F F and Feng, H L Design

and implementation of Log - Gabor filter in fingerprint image enhancement Pattern RecognLett , 29 3 (2008), 301- 308

[8] Wang, S A and Guo Y C A Fingerprint Image

Enhancement Algorithm Based on Wavelet Transform and Median Filter Proceedings of the Second International Symposium on Test Automation & Instrumentation (2008), 719- 723

[9] Wu, C H , Shi, Z X and Govindaraju V Fingerprint image enhancement method using directional median filter

Biometric Technology for Human Identification (2004), 66 -75

[10] Sherlock, B G , Monro, D M and Millard, K Fingerprint Enhancement by Directional Fourier Filtering IEEE Image Sign , 141, 2 (1994), 87 - 94

[11] Hsieh, C T , Lai, E and Wan g, Y C An effective algorithm for fingerprint image enhancement based on wavelet transform P a tt e r n R e c og n 36 2, (2003), 303-312

[12] Hatami S , Hosseini, R , Kamarei M and Ahmadi H Wavelet based fingerprint image enhancement IEEE International Symposium on Circuit Systems (2005) 4610 -4613

[13] Louisa Lam, SeongWhan Lee "Thinning Methodologies A Comprehensive

Survey" IEEE Transactions on Pattern Analysis and Machine Intelligence Vol 14, no 9, pp 869-885, 1992

[14] Dario Maio andDavideMaltoni "Direct Gray-Scale Minutiae Detection in

Fingerprints IEEE Transactions on pattern Analysis and Machine Intelligence

Vol 19, no 1, pp 27-40, 1997

[15] Ton van der Putte and JeroenKeuning Biometrical Fingerprint Recognition',

Fourth Working Conference on Smart Card Research and Advanced Applications

pp 289-303, 2000

[16] ZsoltMiklo Kova CS Vajna A Fingerprint Verification System Based on

Triangular Matching and Dynamic Time Warping' IEEE Transactions on Pattern

Analysis and machine Intelligence, Vol 22, NO 11, pp 1266-1276 2000

[17] MileneArantes, Alessandro Noriaki Ide "A System For Fingerprint Minute

Classification and Recognition" Proceedings of the IFEE International Conference

on Neural Information Processing Vol 5 pp 2474-2478, 2002

[18] Sen Wang Wei Wei Zhang Yang Sheng Wang 'Fingerprint Classification by Directional Fields", Proceedings of the Fourth IEEE International Conference on Multimodal Interfaces, pp 234-239, 2002

[19] SenWang andYangsheng Wang "Fingerprint Enhancement in the Singular Point Area", IEEE Signal Processing Letters Vol 11, no 1, pp 16-19 2004

[20] SharatChikkerur, VenuGovindaraju SharathPankanti Ruud Bolle and Nalini Ratha 'Novel Approaches for Minutiae Verification in Fingerprint Images" Proceedings of the Seventh IEEE Workshop on Applications of Computer Vision pp 456- 462, 2005

[21] Athos Antonelli RaffaeleCappelli, Dario Maio, and DavideMaltoni, Fake Finger Detection by Skin Distortion Analysis IEEE Transactions on information Forensics And Security, Vol 1, no 3, pp 360-373 2006

[22] Jayant V Kulkarni, Jayadevan R Suresh N Mali, Hemant K Abhyankar, and Raghunath S Holambe A New Approach for Fingerprint Classification based on Minutiae Distribution", International Journal of Computer Science, pp 253-258 2006

[23] B Y Hiew, Andrew B J Teoh, and Y H Pang, 'Digital Camera based Fingerprint Recognition" Proceedings of the 2 7 IEEE International Conference on Telecommunications, pp 678-681, 2007

[24] Gualberto Aguilar, Gabriel Sanchez Karinaoscano Moises Salinas, Mariko Nakano and Hector Perez Fingerprint Recognition" Second International Conference on Internet Monitoring and Protection, pp 291-297, 2007

[25] Nicolas Galy, BenoîtCharlot, and Bernard Courtois A Full Fingerprint

Verification System for a Single-Line Sweep Sensor" IEEE Sensors Journal, Vol 7, no 7, pp 1054-1065, 2007

[26] RaffaeleCappelli, Alessandra Lumini, Dario Maio, and DavideMaltoni "Fingerprint Image Reconstruction from Standard Templates , IEEE Transactions on Pattern Analysis and Machine Intelligence Vol 29 no 9, pp 1489-1503 2007

[27] Anil K Jain, Fellow Yi Chen and MeltemDemirkus, Pores and Ridges High-Resolution Fingerprint Matching Using Level 3 Features ', IEEE Transactions on Pattern Analysis and Machine Intelligence Vol 29, no 1, pp 15-27, 2007

[28] Liu Wei, Chen Yonghui, Wan Fang, "Fingerprint Classification by Ridgeline and Singular Point Analysis Congress on Image and Signal Processing, pp 594-598 2008

[29] ShubhangiVaikole S D Sawarkar, ShilaHivrale Taruna Sharma, Minutiae Eetracion from Fingerprint Images', IEEE International Advance Computing Conference, pp 691-696, 2009

[30] H B Kekre, V ABharadi "Fingerprint s Core Point Detection Using Orientation Field", International Conference on Advances in Computing, Control and Telecommunication Technologies pp 150-152, 2009

[31] Ishmael S Msiza, BrainLeke-Betechuoh, Fulufhelo V Nelwamondo andNtsikaMsimang "A Fingerprint Pattern Classification Approach Based on the Coordinate Geometry of Singularities", Proceedings of the 2 9 IEEE International Conference on Systems, Man, and Cybernetics, pp 516-523, 2009

[32] R Thai Fingerprint image enhancement and minutiae extraction 2003

[33]Shila Samantaray "A DoG based approach for fingerprint Image Enhancement Ph D Thesis Department of Computer Science and Engineering NIT Rourkela, 2011