FINGERPRINT RECOGNITION BY MINUTIA MATCHING

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DECLARATION

In accordance with the requirements of the degree of Bachelor of Electronics and Communication Engineering in the Division of Computer Science and Engineering, I am presenting this thesis paper entitled, 'FINGERPRINT RECOGNITION BY MINUTIA MATCHING'. This project has been performed under the supervisor of Dr. Tarik Ahmed Chowdhury.

I hereby declare that this thesis is based on the results found by myself. Materials of work found by other researcher are mentioned by reference. This thesis, neither in whole nor in part, has been previously submitted for any degree.

Signature of	Signature of
Supervisor	Author
(Dr. Tarik Ahmed Chowdhury)	(Dilruba Sharmeen)

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I also would like to thank all others who gave me support for the thesis or in other aspects of my study at BRAC UNIVERSITY.

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ABSTRACT

In this thesis a current technique for fingerprint recognition has been investigated. It includes image preprocessing, feature extraction, post processing and feature match. For each sub-task some methods like-Image enhancement, image binarization, image segmentation and some morphological operations has analyzed. Based on the analysis, an integrated solution for fingerprint recognition is developed for demonstration.

The demonstration program has coded using MATLAB 7.1. The performances have shown by experiments conducted upon a variety of fingerprint images. Also, the experiments illustrate the key issues of fingerprint recognition that are consistent with this conversation.

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1.0 INTRODUCTION

1.1 INTRODUCTION to BIOMETRICS:

1.1.1 Biometric System:

Positive identification of individuals is crucial societal requirement. Until recently, automatic personal identification technologies followed two approaches: *i) a token based approach* and *ii) a knowledge based approach*. Token based approaches are based on identification using tokens such as a magnetic swipe card, key, driver's license, etc. knowledge-based approaches use passwords and personal identification numbers (PINs) to identify or validate a person's identify. Both these forms of identification are not secure, because this credential's can be lost, stolen or duplicated. On the other hand, biometrics is a science of verifying and establishing the identity of an individual through physiological features or behavioral characteristics that are unique to that individual and hence cannot be stolen, lost or misused. The word "Biometric" is derived from the Ancient Greek language where "Bio" means "life "and "Metric" means "To measure". All Biometric systems compare a biometric sample against a previously stored template to determine a level of similarity. Biometric identification works on the principle of a threshold. Because, it is nearly impossible to capture the biometric the same way every time it is used for access. Therefore, the system cannot expect a 100% match. Instead, a threshold system is used that can be modified depending on the security level of the applications. If the score exceeds the threshold, the result is a match and if the score falls below the threshold, the result is non-match.

Biometric characteristics can be divided in to two main classes, as represented in the following figure [1.1.1]:

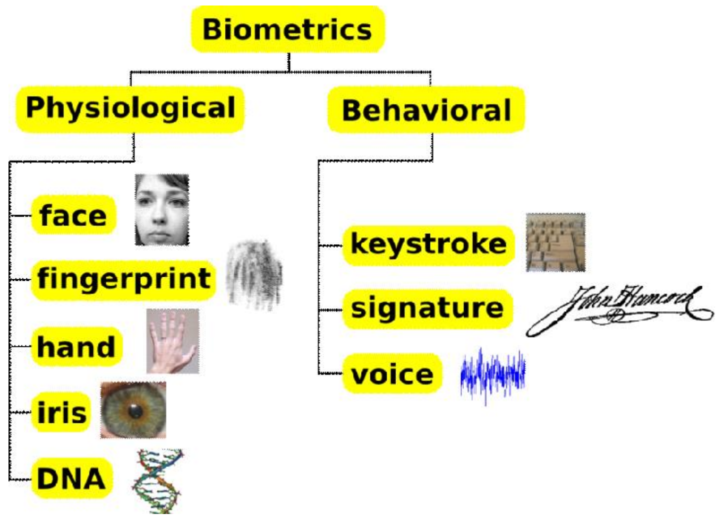


Fig 1.1.1: Classification of Biometrics

- **Physiological Biometrics:**
  These characteristics are related to the structure of the body, such as, ***Fingerprint***, face, Irish, Hand geometry, DNA, etc.

- **Behavioral Biometrics:**
  These characteristics are related to the behavior of a person, such as, Handwriting, Voice, Gait, Signature, keystroke, etc. [1] [2]

1.1.2 Why Fingerprints are so *Good* for use in Biometrics?

There are many criteria that must be accounted before a physical or behavioral trait can be considered suitable for use in biometrics. Perhaps the most important criteria are *"Uniqueness"* and *"Permanence"*. Fingerprints have been well proven on both counts.

- **Uniqueness:**
  Uniqueness of fingerprint is not an established fact but an empirical observation. Fingerprints have been routinely compared worldwide for more than

140 years. In that time, no two fingerprints on any two persons have been found to be identical. Even identical twins who shared same DNA structure have different finger prints; they tend to have fingerprints that are similar globally, i.e. have the same fingerprint classes (e.g.. whorl, loop, arch, etc) but ridge structures are very different. The true is also holds for the right and left finger and can be anticipated for clones. [1] [2] [5]

- **Permanence:**

Fingerprints are fully formed at about seven months of fetus development and finger ridge configuration do not change throughout the life of an individual except due to accidents such as bruises and deep physical injuries. They simply expand proportionately in all directions as we grow, means fingerprints maintains a proportional scale for its entire existence. [2] [6]

The other advantages of fingerprints as a biometric are stated bellow: [8]

- **High Universality:**

  Within human population every individual has fingerprint which can be easily used for their authentication.

- **High Indispensability:**

Like token-based authentications fingerprints for human identification does not lead problems of being stolen or lost. On the other hand fingerprints would never be forgotten like PINs, password, or other knowledge-based systems. Actually in most cases, fingerprints would accompany the individual throughout his/her life time unless there is some serious injury to their fingers.

- **High Collectability:**

Fingerprints can be easily collected compared to other biometric samples, such as Retina, DNA, Irish, etc. which require complete cooperation and high cost special equipment to acquire the biometric samples. On the other hand the process of fingerprint acquiring requires minimal or no user training and can be collected easily from both cooperative and non cooperative users.

- **Good Storability:**

The database of fingerprints does not require huge space; it depends on the representation of the templates that can be chosen for the system. Depending on the application and way of representation the size of these templates can be from 52 bytes to several megabytes.

- **High Performance:**

Fingerprints remain one of the most accurate biometric modalities considering both False Accept Rate (FAR) and False Reject Rate (FRR).

- **Wide Acceptability:**

Since the beginning of the twentieth century, fingerprints have been formally accepted as valid personal identification trait and have become a standard routine in forensics.

1.2 INTRODUCTION to FINGERPRINT:

1.2.1 What is a FINGERPRINT?

A fingerprint is an impression of the friction ridges found on the inner surface of a finger or thumb. Fig [1.2.1] Finger skin is made of friction ridges, with pores (sweat glands). Friction ridges are created during foetal live and only the general shape is genetically defined.

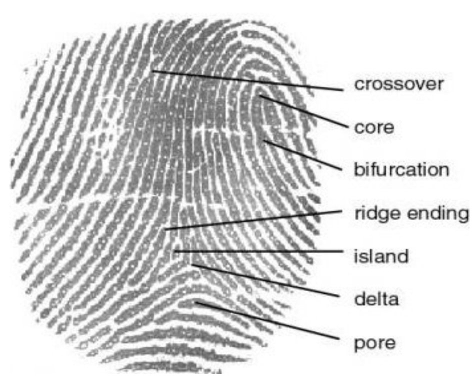


Figure1.2.1: A fingerprint image labeled with different components.

A fingerprint is composed of different types of components [8]. Those are stated bellow-

- **Ridges**: The lines that flow in various patterns across fingerprints are called *‘Ridges*’.
- **Furrows**: The spaces between ridges are called *‘Furrows*’ or *‘valleys’*. It dos not make contact with a surface under normal touch.
- **Termination**: The point on a fingerprint that a friction ridge begins or ends without splitting into two or more continuing ridges or it is the immediate ending of a ridge, at which a ridge terminates.
- **Bifurcation**: It is the point on the ridge from which two branches derive. Bifurcation is also known as *‘Ridge Branch’*.
- **Dots**: They are very small ridges.
- **Islands**: Ridges those are slightly longer than dots, occupying a middle space between two temporarily divergent ridges.
- **Ponds or lakes**: A notch protruding from a ridge.
- **Bridges:** Small ridges joining two longer adjacent ridges.
- **Crossover:** Two ridges which crosses each other.
- **Core:** The core is the inner point, normally in the middle of the print, around which swirls, loops, arches center.
- **Delta:** Deltas are the points, normally at the lower left or right hand of the fingerprint, at which a triangular series of ridges center.

However, shown by intensive research on fingerprint recognition fingerprints are distinguished by *‘MINUTIA’*, which are some abnormal points or the discontinuities of the ridges. There are among 150 different types of minutiae categorized based on their configuration. [Fig1.2.2]

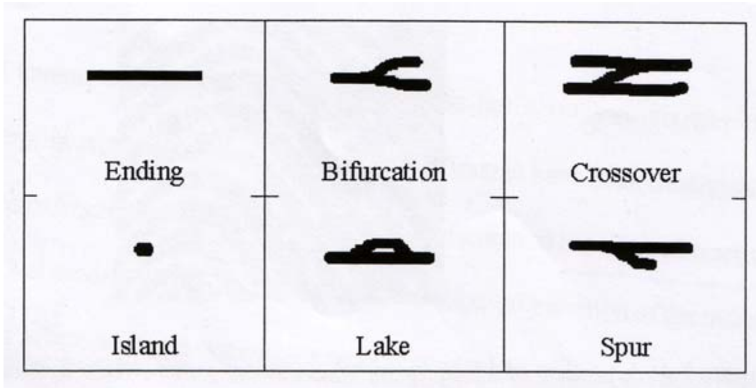


Fig1.2.2: Some of the common minutiae types

Among these minutia types *'Termination or Ridge Ending'* and *'Bifurcation'* are mostly significant and have heavy usage [Fig1.2.3]. There are features that can be used for matching such as core, delta, pores but they are not available on all fingerprints beside requires higher resolution scanner and very good image quality. Whereas, minutia is relatively stable and robust to contrast, image resolutions and global distortion compared to other representations. However, to extract the minutia from a poor quality image is not an easy task. [1][2]

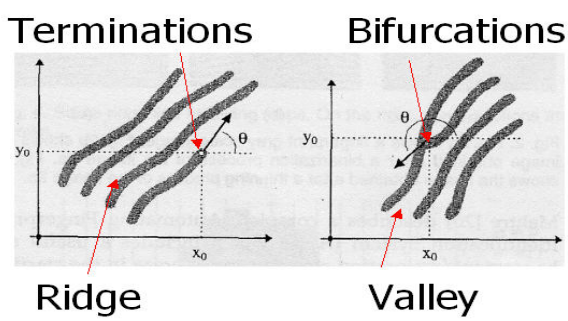
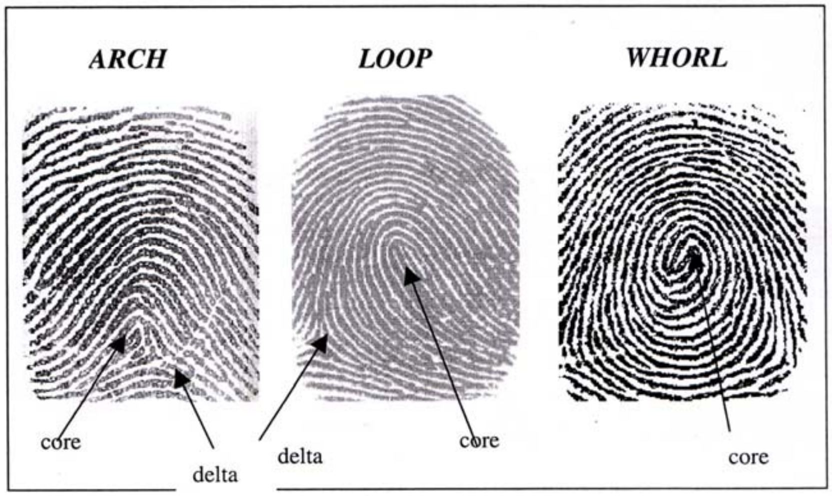


Figure1.2.3: Minutia: Termination and Bifurcation

1.3 Fingerprint Patterns:

The ridge flow constitutes a global pattern of the fingerprint and based on the structure of ridges the fingerprints can be categorized in three patterns i*) Arch*, *ii) Loop* and *iii) Whorl*. [Fig1.3.1] Different classification schemes can use up to ten or so pattern classes, but these three are the basic patterns. [2]



:

Fig1.3.1: Fingerprint Patterns: Arch, Loop, Whorl

1.4 What is Fingerprint Recognition?

The fingerprint recognition problem can be separated in to two categories [Fig 1.4.0]: *i) Fingerprint Verification ii) Fingerprint Identification.*

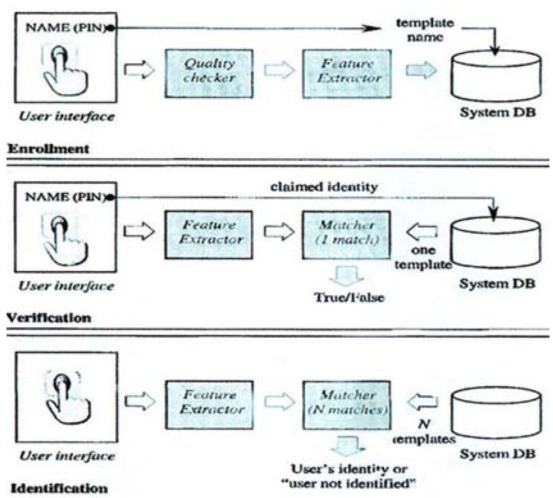


FIG1.4.0: Block diagrams of enrollment, verification and Identification tasks.

- **Fingerprint Verification:**

It is the comparison of a claimant fingerprint against an enrollee fingerprint, where the intention is that the claimant fingerprint matches the enrollee fingerprint. A verification system either rejects or accepts the submitted claim or identity (*Am I whom I claim I am?*) .To prepare for verification, a person initially enrolls his or her fingerprint into the verification system. A representation of that fingerprint is stored in some compressed format along with the person's name or other identity. Subsequently, each access is authenticated by the person identifying him or herself, then applying the fingerprint to the system such that the identity can be verified. Verification is also termed '*one-to-one matching'*. It is suitable for used in civilian applications like, PC access, credit cards, personal identification, etc.[1][3][6]

- **Fingerprint Identification:**

Fingerprint Identification is to specify one person's identity by his fingerprint. (*Who am I?*). Without any information of the person's identity, the fingerprint Identification system tries to match his fingerprint with those in the whole fingerprint database. It is especially useful for criminal investigation cases. Identification is also termed as *'one-to-many matching'*.

There is an informal third type of matching that is termed *'one-to-few matching'*. This is for the practical application where a fingerprint system is used by 'a few' users, such as by family members to enter their house. A number that constitutes 'few' is usually accepted to be somewhere between 5 and 20.

However, all fingerprint recognition problems are ultimately based on a well representation of a 'one-to-one matching'. As long as the representation of fingerprints remains the uniqueness and keeps simple, the fingerprint matching is straightforward and easy. [3][6]

1.4.1 What is the scheme to avoid False Rejection in a Fingerprint Authentication System?

The finger should be clean that means free of sticky residue and greases and depending on the sensor should not be too damp or too dry. The finger should always be applied on the sensor in the same manner (same position and direction) and with uniform pressure (e.g., avoid pressuring while twisting) [5]

1.4.2 How do Wounds affect Fingerprint Recognition?

If a wound is not too deep, the finger lines will fully regenerate to their original state. Deep cuts leave line forming scars and should be recognized as such by good identification algorithms, thereby barely impairing the identification performance. Most system offers the possibility to record a *'Substitute Finger'* in enrollment, so that a fingerprint authentication can still take place during healing process. [6]

1.5 Three Approaches for Fingerprint Recognition:

The large number of approaches to fingerprint matching can be coarsely classified into three families.

i) Minutiae- based Matching:

This is the most popular and widely used technique, being the basis of the fingerprint comparison made by fingerprint examiners. This approach represents the fingerprint by its local features. Each Minutia may be described by a number of attributes, including its location in the fingerprint image, orientation, type (e.g., ridge termination or ridge bifurcation), a weight based on the quality of the fingerprint image in the neighborhood of the minutia and so on. Minutiae are extracted from the two fingerprints and stored as sets of points in the two dimensional plane. Minutiae based matching essentially consists of finding the alignment between the template (the representation of fingerprint acquired during enrollment is denoted as

TEMPLATE) and the input (the representation of fingerprint to be matched is denoted as INPUT) minutia sets that results in the maximum number of minutiae pairings.

Minutia based fingerprint representation and matching are widely used by both machine and human experts because of several advantages compared to other fingerprint representations. Such as, its configuration is highly distinctive and minutiae based systems are more accurate than correlation based systems and the template size of minutia based fingerprint representation is small. Minutia based fingerprint representation also has an advantage in helping privacy issues, since one cannot reconstruct the original image from using only minutiae information. As the minutia are predominantly randotypic in nature and cause most of the uniqueness in a fingerprint, therefore either directly or indirectly almost all fingerprint system examines minutia. But, reliably extracting minutia from poor quality fingerprints is very difficult and minutiae extraction is also time consuming.

Because of the advantages of minutia based fingerprint matching and as it is the backbone of the current available fingerprint recognition products, in this thesis *'Minutia-based matching'* was applied**.** [1][2][3]

ii) **Correlation-based** matching**:**

In this approach two fingerprint images are superimposed and the correlation between corresponding pixels is computed for different alignments (e.g., various displacements and rotations). This approach is computationally very expensive and also complex. [1]

ii) Ridge Feature-based Matching:

The other features of the fingerprint ridge patterns e.g., local orientation and frequency, ridge shape, texture information can be extracted more reliably than minutiae but their distinctiveness is generally lower. The approaches belonging to this family compare fingerprint in terms of features extracted from the ridge pattern. In principle, correlation and minutiae-based matching could be conceived as subfamilies of ridge feature-based matching, inasmuch as the pixel intensity and the minutiae positions are themselves features of the finger ridge pattern. [1]

In this Thesis, Chapter Two will review different techniques for Fingerprint Recognition methods. Chapter Three analyze the system design for fingerprint recognition process. Chapter Four will discuss the Fingerprint Image Pre-processing stage. Chapter Five will discuss different steps for Minutia Extraction. Chapter Six examine the Fingerprint Image Post-processing stage. Chapter Seven will evaluate the Minutia Match stages. Chapter Eight will analyze the performance measurement and the experimentation results. Finally, thesis will be concluded in Chapter Nine.

2.0 Minutia-based other Techniques

2.1 Direct Gray-Scale Minutiae Extraction:

Approaches that directly work on gray-scale images to extract are proposed to overcome some of the problems caused by fingerprint binarization and thinning. Most of these algorithms are based on ridge tracing. Given a starting point (x_o, y_o) and a direction θ_0, the method of Maio et al. tracks the ridges in the gray scale image by sailing according to the local orientation of the ridge pattern.

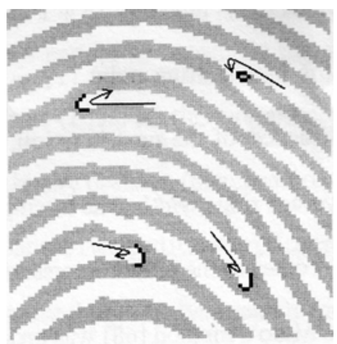


Fig 2.1.1: Minutiae are located in the contours by looking for *significant turns*. A ridge ending is detected when there is a sharp left turn; whereas the ridge *bifurcation* is detected by a sharp right turn

The algorithm computes the next ridge point (x_t, y_t) by moving μ pixels on the direction θ_0. Since (x_t, y_t) is only an approximation the method then analyze the gray-scale profile of the section set Ω (whose direction is orthogonal to θ_0, length is (2þ+1) and the median is (x_t, y_t) and uses the local maxima on Ω as the new starting point (x_1, y_1) and the local ridge direction at (x_1, y_1) as the new start direction of the next iteration. The parameters μ and *þ* are determined according to the average ridge width. The tracing is extracted in the direction of a ridge and stop when a ridge comes to the end or intersects with other ridges. [2]

(a) (b (c)

Fig 2.1.2: (a) Original Image; (b) the contour representation of the image; (c) detected minutiae superimposed on the contour image. [2]

2.2 Minutiae Matching with Pre-Alignment:

Embedding fingerprint alignment in to the minutia matching stage certainly leads to the design of robust algorithms, which are often able to operate with noisy and incomplete data. On the other hand, the computational complexity of such methods does not provide a high a matching throughput. Storing pre-alignment templates in the database and pre-aligning the input before the minutia matching can be a valid solution to speed up the 1: N identification. In theory, if a perfect pre-alignment could be achieved, the minutia matching could be reduced to a simple pairings. [1]

Two main approaches for pre-aligning have been investigated**.**

i) Absolute Pre-Alignment:

In this process, before storing in the database each fingerprint template is pre-aligned, independently of the others. Matching an input fingerprint ***I*** with a set of templates requires ***I*** to be independently registered just once, and the resulting aligned representation to be matched with all the templates. The most common absolute pre-alignment technique translates the fingerprint according to the position of the core point. Unfortunately, reliable detection of the core is very difficult in noisy images in arch type patterns, and a registration error at this level is likely to result in matching error. Absolute Pre-alignment with respect to rotation is even more critical; some authors proposed using the shape of the external fingerprint silhouette (if available), the orientation of the core delta segment (if delta exists), the average orientation in some regions around the core or the orientation of the singularities. In any case, no definite solution has been proposed for a reliable pre-alignment to date and, therefore, the design of a robust system requires the minutiae matcher to tolerate pre-alignment errors to some extent. [1]

ii) Relative Pre-Alignment:

The input fingerprint ***I*** has to be pre-aligned with respect to each template ***T*** in the database; 1: N identification requires N independent pre-alignments. Relative pre-alignment may determine a significant speed up with respect to the algorithms that do not perform any pre-alignment, but cannot complete in terms of efficiency with absolute pre-alignment. However, relative pre-alignment is in general more effective (in terms of accuracy) than absolute pre-alignment, because the features of the template ***T*** may be used to drive the registration process. [1]

2.3 Minutiae Matching Avoiding Alignment:

Fingerprint alignment is certainly a critical and time-consuming step. To overcome problems involved in alignment, and to better cope with local distortion, some authors perform minutia matching locally. A few other attempts have been proposed that try to globally match minutia without requiring explicit recovery of the parameters of the transformation. Bazen and Gerez introduced in *Intrinsic Coordinate System* (ICS) whose axes run along hypothetical lines defined by the local orientation of the fingerprint patterns. First, the fingerprint is partitioned in regular regions (i.e, regions that do not contain singular points). In each regular region, The ICS is defined by the orientation field. When using intrinsic coordinates instead of pixels coordinates, minutiae are defined with respect to their position in the orientation field. Translation, displacement and distortion move minutiae with the orientation field they are immersed in and therefore do not change their intrinsic coordinates. On the other hand, some practical problems such as reliably partitioning the fingerprint in the regular regions and unambiguously defining intrinsic coordinate axes in low-quality fingerprint images still remains to be solved.[1]

3.0 SYSTEM DESIGN

3.1 System level Design:

A fingerprint recognition system constitutes of three divisions [Fig 3.1.0]:

1. Fingerprint Acquiring Device

2. Minutia Extractor

3. Minutia Matcher

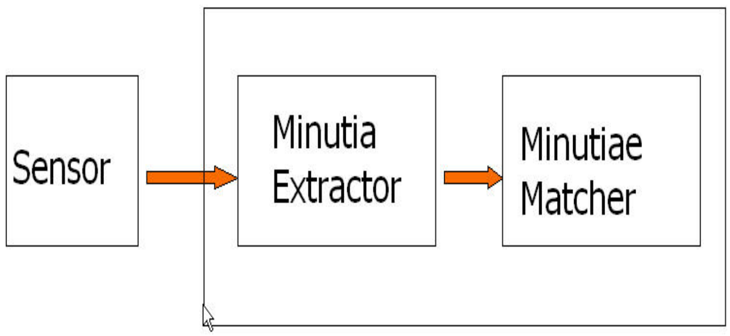


Fig 3.1.0: Simplified Fingerprint Recognition System

3.1.1 Fingerprint sensing and storage:

For fingerprint acquisition, Optical or semi conductor sensors are widely used. All fingerprint sensors try to generate a digital picture of the finger surface. This picture normally has a pixel resolution of 500 dpi. The picture generation can be different for every type of sensors.

Fingerprint images can be classified by their acquisition methods as either *Inked* or *Off-Line* and *Live Scanned* or *Online*. [2][3][10]

i) Inked or Off-line:

An off-line image is typically obtained by smearing ink on the fingertip and creating an inked impression of the fingertip on paper. The inked impression is then digitized by scanning the paper using an optical scanner or a high quality video camera. Ink-technique is mainly used in forensic applications. [2][3][10]

ii) Live scanned or Online:

A Live-scan image is acquired by sensing the tip of the finger directly, using a sensor that is capable of digitizing the fingerprint on contact. Live-scan technology is one of the main contributions to the extraordinary progress of fingerprint recognition. [Fig 3.1.1] Especially the invention of user friendly, low-cost, reliable and compact fingerprint scanners, which makes fingerprint recognition technologies rapidly expand into civilian applications. Live-scan fingerprint scanners can be classified as Optical sensors, capacitive sensors, Ultrasound Sensors, Thermal Sensors. They have high efficiency and acceptable accuracy except for some cases that the user's finger is too dirty or dry.

There are other types of sensors that utilize other techniques such as high-quality cameras, electric field or piezoelectric materials exist but are not mature enough for large scale applications. [2][3][10]

Fig 3.1.1: Some Modern Live Scanner

3.1.2 Which type of sensor is the best?

This question unfortunately offers no definite answer, as every application has different requirements and each type of sensor has its specific advantages and also disadvantages. The following criteria can assist in reaching an answer [6]:

- Cost
- Degree of maturity
- Image quality in sub optimal conditions
  - Indoor/outdoor
  - Personal/public
  - Normal/abnormal fingers
  - Dry/moist fingers
- Size, the size of fingerprint generally determines the cost of a sensor.
- Sensitivity against vandalism
- Temperature resistance
- Sensitivity against forgery
- ESD (electrostatic discharge) Sensitivity

However, the testing database for this thesis was collected from the fingerprints provided by FVC2002 (Fingerprint Verification Competition 2002). So, no sensing stage has implemented.

3.2 Algorithm level Design:

To implement a minutia extractor, three-stage approaches have applied in this thesis [Fig 3.2.1]. They are:

i) Pre-Processing

ii) Minutia Extraction

iii) Post-Processing

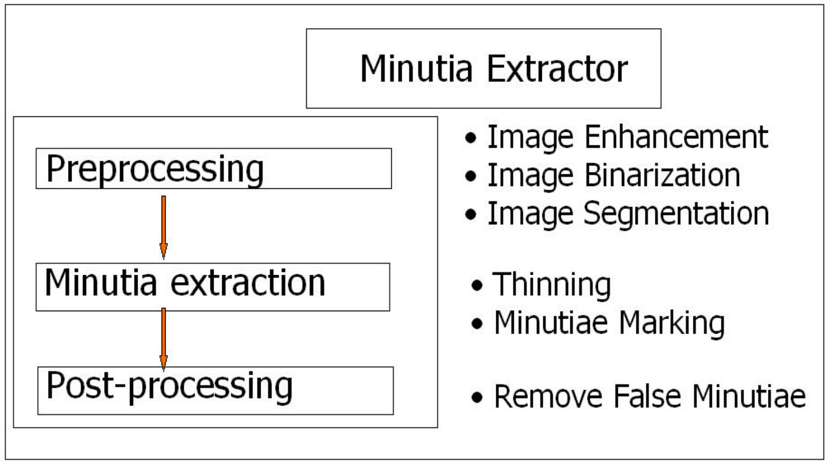


Fig 3.2.1: Minutia Extractor

For the fingerprint image pre-processing stage, Histogram Equalization and Fourier Transformation has applied for image enhancement. Minutia extraction algorithm are of two types i) Binarized-based extraction and ii) Gray-Scale based extraction. In this thesis Binarized-based extraction has applied and the fingerprint image was Binarized by using the locally adaptive threshold method [8].Region of Interest extraction and Thinning was done by applying some Morphological operations. For post-processing stage a novel representation for bifurcation has used to unify and Terminations and Bifurcations.

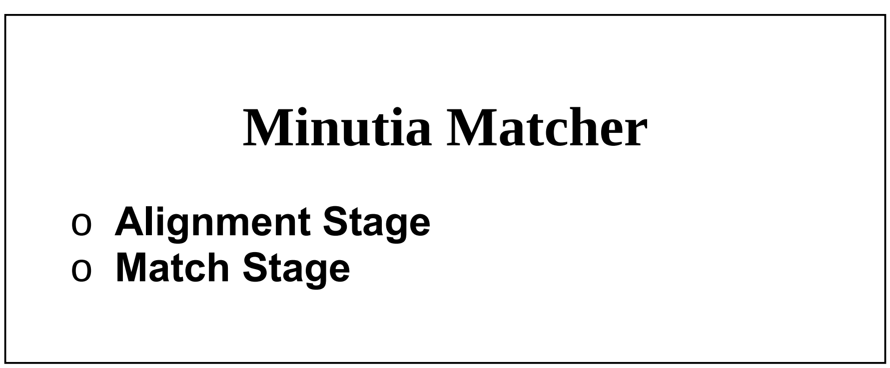


Fig 3.2.2: Minutia Matcher

The Minutia matcher chooses any two minutiae as a reference minutia pair and then matches their associated ridges first. If the ridges match well, two fingerprint images are aligned and matching is conducted for all remaining minutia. [Fig 3.2.2]

4.0 FINGERPRINT IMAGE PRE-PROCESSING

4.1 Fingerprint Image Enhancement:

A fingerprint image is one of the nosiest of image types. This is due to predominantly to the fact that fingers are our direct form of contact for most of the manual tasks we perform, finger tips become dirty, cuts, creased, dry, wet, and worn, etc and also the fingerprint images acquired by from sensors or other medias are not assured perfect quality. But fingerprint image quality is an important factor in the performance of minutiae extraction and matching algorithms. A good quality fingerprint image has high contrast between ridges and furrows whereas a poor quality fingerprint image is low contrast, smudgy, causing spurious and missing minutiae. The goal of fingerprint Image enhancement is to reduce these noises and to improve the clarity of the ridge structure in a fingerprint. It also connects the false broken points of ridges due to insufficient amount of ink which is very useful for higher accuracy to fingerprint recognition. [2][3]

General purposes of mage enhancement techniques are not very useful due to the non-stationary nature of a fingerprint image. However, techniques such as Gray-Level Smoothing, Contrast Stretching, Histogram Equalization, Fourier Transform and Wiener filtering can be used for pre-processing steps. [2]

Two methods have adopted in this thesis for Fingerprint Image enhancement:

1. **Histogram Equalization**
2. **Fourier Transformation**

i) Fingerprint Enhancement by Histogram Equalization:

To transform the gray levels so that the histogram of the resulting image is equalized to be a constant. The purposes of Histogram Equalization are
i) Equally use all available gray levels and ii) for further Histogram Specifications. Depending upon the fingerprint capture device, the image can have a range of specifications. Commonly, the pixels are 8-bit values and this yields an intensity range from 0 to 255.The original histogram of a fingerprint image has the bimodal type but the histogram after the Histogram Equalization occupies all the ranges from 0 to 255. [Fig 4.1.1]

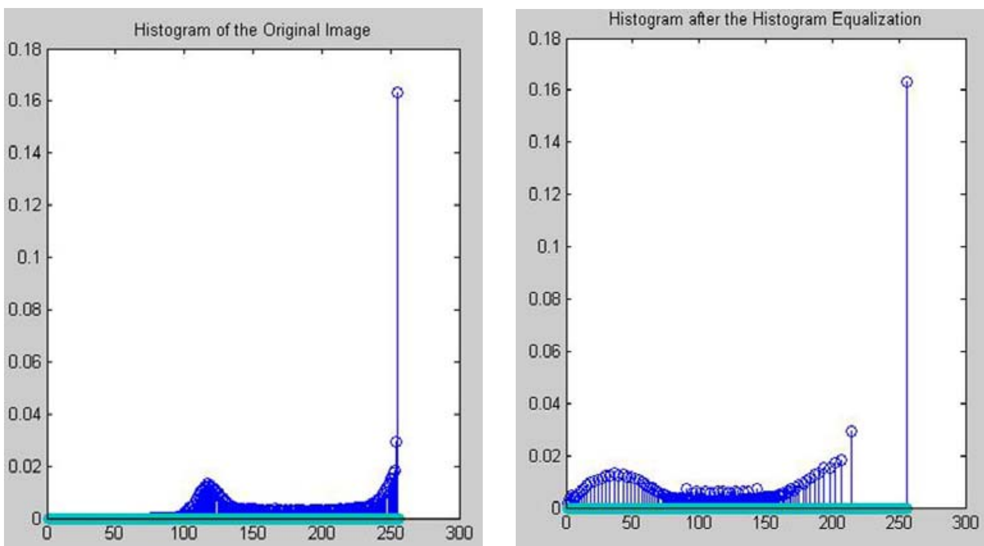


Fig 4.1.1: The original Histogram of the Fingerprint Image (left side), the Histogram after the Histogram Equalization (right side)

Histogram equalization is to expand the pixel value distribution of an image so as to increase the perceptional information. [Fig 4.1.2] illustrate the image after applying Histogram Equalization.

Fig 4.1.2: Original Fingerprint Image (left side), Image after applying the Histogram Equalization (right side)

ii) Fingerprint Enhancement by Fast Fourier Transform (FFT):

In FFT based fingerprint enhancement method instead of explicitly computing the local ridge direction and frequency, enhancement is achieved by multiplying the Fourier Transform of the block by magnitude of power **'k'.** [Fig 4.1.3]

At first **dividing** the whole image into small processing blocks (32 by 32) pixels; the Fourier Transform was performed according to:

$$F(u,v) = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y) \times \exp\{-j2\pi \times [(ux \div M) + (vy \div N)]\}$$

… … … (1)

for **u** = 0, 1, 2, ….31 and **v** = 0, 1, 2, ….31

In order to enhance a specific block by its dominant frequencies, the FFT of the block was multiplied by its magnitude a set of times. Where the magnitude of the original is

FFT = abs (F(u,v)) = |((u,v)|

Get the enhanced block according to

$$g(x,y) = F^{-1}\{F(u,v) \times |F(u,v)|^{k}\} \quad \text{……… (2)}$$

where $F^{-1}(F(u,v))$ is done by:

$$F(u,v) = (1/MN)\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y) \times \exp\{-j2\pi \times [(ux \div M) + (vy \div N)]\} \quad \text{..(3)}$$

for x = 0, 1, 2, ….31 and y = 0, 1, 2, ….31.

The ***'k'*** in formula (2) is an experimentally determined constant, which was chosen here k = 0.9 to calculate. While having a higher *'k'* improves the appearance of the ridges, filling up small holes in ridges, having too high a *'k'* can result in false joining of ridges. Thus a termination might become a bifurcation.

Fig 4.1.3: Image enhancement by Histogram Equaliztion (left side), Image enhancement by FFT (right side)

The enhanced image after FFT has the improvements to connect some falsely broken points on ridges and to remove some spurious connections between ridges. [Fig 4.1.3] illustrates the Fingerprint Image after Fourier Transformation. The side effect of each block is obvious but it has no harm to the further operation because the image after consecutive Binarization is pretty good as long as the side effect is not too severe.

4.2 Fingerprint Image Binarization:

The Binarization operation takes as input a gray-scale image and returns a binary image as output. The image is reduced in intensity levels from the original 256 (8 bits per pixel) to 1 (2 bits per pixel), black and white. [2]

In Fingerprint Image Binarization the ridges in the fingerprint are highlighted with black color and furrows are white. The difficulty in performing Fingerprint Image Binarization is that all the Fingerprint Images do not have the same contrast characteristic and contrast may vary within a single image, so choosing a global threshold for all pixels is impossible. That's why Adaptive techniques are preferred in general.

In this thesis a locally adaptive Binarization was applied to binarize the fingerprint image [Fig 4.2.1] which transforms a pixel value to 1 if the value is larger than the mean intensity value of the current block (16 x16) to which the pixel belongs and this way the threshold changes dynamically over the Image. [2][3].

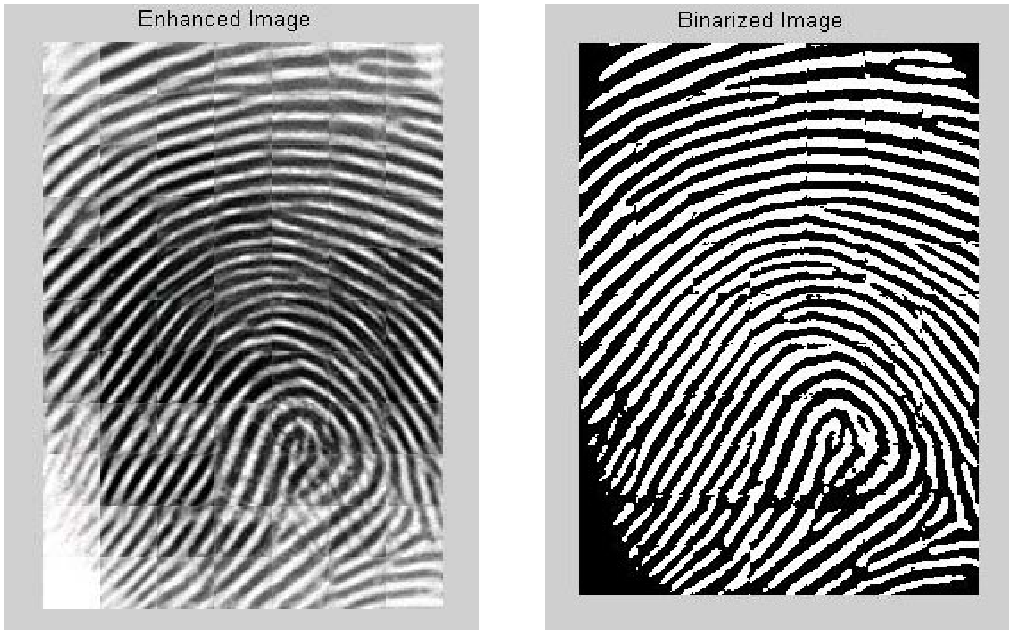


Fig 4.2.1: Fingerprint Image after ADAPTIVE BINARIZATION

Enhanced Gray Image (left side), Binarized Image (right side)

4.3 Fingerprint Image Segmentation:

Image Segmentation means to separate out the regions of the image corresponding to objects in which we are interested, from the regions of the image that corresponds to background [7].

In general, only a Region of Interest (ROI) is useful to be recognized for each fingerprint image. The image area without effective ridges and furrows is first discarded since it only holds background information. Then the bound of the remaining effective area is sketched out since the minutiae in the bound region are confusing with those spurious minutiae that are generated when the ridges are out of the sensor [1].

4.3.1 Morphology:

Morphology is a tool for extracting Image components that are useful in the representation and description of region shape such as boundaries, skeletons and the convex hull. Morphological techniques are also used for pre or post processing such morphological Thinning, Filtering and Pruning [4].

- **Region of Interest (ROI) by MORPHOLOGICAL Operations:**

Two MORPHOLOGICAL Smoothing Operations called *'OPEN'* and *'CLOSE'* are adopted [Fig 4.3.1]. The *'OPEN'* operation can expand images and remove peaks introduced by backgrounds noise. The *'CLOSE'* operation can shrink images and eliminate small holes or cavities. Here Opening was followed by Closing to remove or attenuates both bright and dark artifacts to make image smoother. [3][4]

Fig 4.3.1: Fingerprint Image after Segmentation

Binarized Image (left side), Image after Opening-Closing and Excluding Boundary (right side)

5.0 Minutia Extraction:

5.1 Fingerprint Ridge Thinning:

Usually, the Binarized-based minutia extraction methods apply a thinning algorithm after the binarization step to obtain the 'Skeleton' of fingerprint ridges. Thinning means reducing binary objects or shapes in an image to strokes that are a single pixel wide. As the fingerprint ridges are fairly thick, so it is desirable for subsequent shape analysis to thin the ridges so that each is one pixel thick and the single-pixel width ridges facilitate the job of detecting endings and bifurcations.

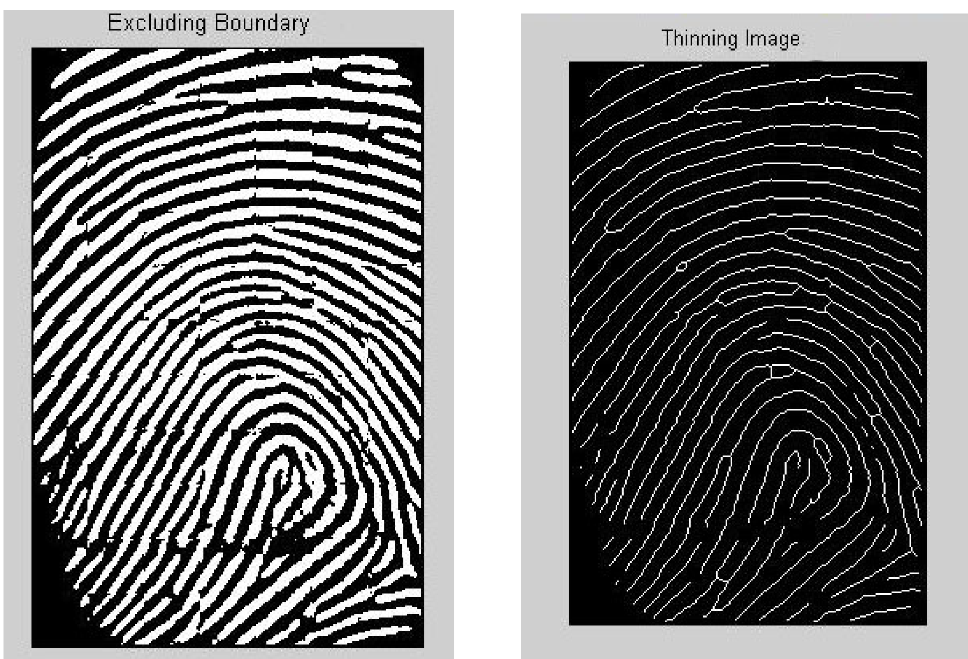


Fig 5.1.1: Fingerprint Image after Segmententation (left side), Image after Ridge Thinning (right side)

The thinning method will reduce the ridges width while retaining connectivity and minimizing the number of artifacts introduced due to this processing. These artifacts are comprised primarily of spurs, which are enormous bifurcations with one very short branch. [4]

In this Thesis, thinning for ridges has been done using the '*bwmorph'* function of MATLAB. [Fig 5.1.1] shows the thinned ridges of fingerprint image after applying '*bwmorph'* function in the binarized segmented image.

The thinning image is than filtered by other three morphological operations to remove some ***H-breaks***, ***isolated points***, ***spurs*** **and** ***spikes***.

5.2 Connected Component-Labeling:

The method of identifying objects in a binary image is known as *'LABELING'*. It scans and groups its pixels into component based on pixel connectivity (describes a relation between two or more pixels) , i.e. all pixels in connected component share similar intensity values and are in some way connected with each other. Once all groups have been determined, each pixel is labeled with a gray level or a color according to the component it was assigned to. Connected component labeling works on both binary and gray level images and different measures of connectivity are possible. However, in this Thesis the input was binarized thin image and 8-connectivy has used. [4]

Fig 5.2.1 shows the fingerprint image after labeling.

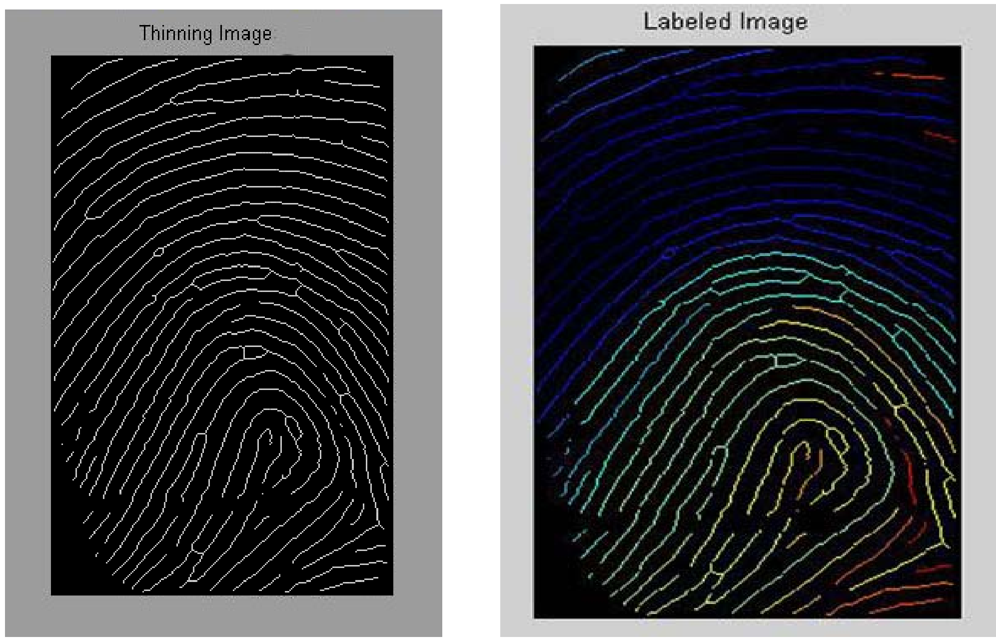


Fig 5.2.1: Fingerprint Image after Labeling

Thinned Image (left side), Image after Labeling (right side)

5.3 Minutia Marking:

The fingerprint minutiae are found operating upon the thinned image and straightforward to detect. Endings are found at terminations points of thin lines and Bifurcations are found at the junctions of three lines. Minutia can be detected by examining the 8-neighborhood of ridge thin pixel at (x,y) and classified as:

- a Ridge Ending if $\sum_{i.j = -1 \ldots 1} I(x+i, y+j)=1$
- a Ridge Bifurcation $\sum_{i,j = -1 \ldots 1} I(x+i, y+j)=3$

In general, for each 3x3 window, if the central pixel is '1' and has exactly three '1' value neighbors, then the central pixel is considered as a Ridge Branch. [Fig 5.3.1]

If the central pixel is '1' and has only one '1' value neighbor, then the central pixel is considered as a Ridge Ending. [Fig: 5.3.2]

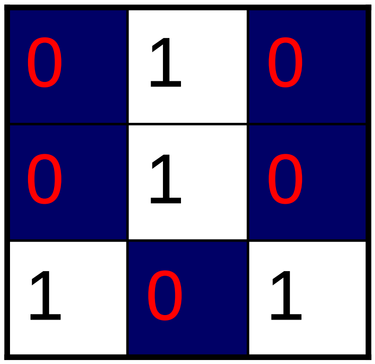


Fig: 5.3.1: Bifurcation

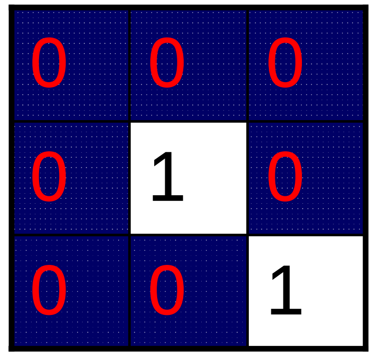


Fig 5.3.2: Termination

5.4 Average Inter-Ridge Width:

The average distance between two neighboring ridges is referred as Average Inter-Ridge Width- '***D'***. It was approximated by scanning a row of thinned image and summing up all the pixels in the row whose value is one '1'. After that divide the row length with the above summation to get an average inter- ridge width. Such kind of operation was also performed on columns. Finally the inter-ridge width for rows and columns were averaged to get the ***'D'***.

60 FINGERPRINT IMAGE POST-PROCESSING

61 False Minutia Removal:

The pre-processing stage does not absolutely cure the fingerprint image. There will always be extraneous minutia found due to a noisy original image or due to artifacts introduced by all the earlier stages which leads to spurious minutia. Like, Thinning tends to introduce hair-like artifacts along the one pixel wide skeleton, which leads to detection of spurious minutia. Sensing system can also introduce false minutia. Such as in Live Scan, residues can be left over on the glass platen from the previous fingerprint capture and on the other hand in Off-Line fingerprint images, false ridge breaks due to insufficient amount of ink and ridge cross-connects due too over inking. So these false minutiae will significantly affect the accuracy of matching if they are simply considered as genuine minutia. So some mechanisms of removing false minutia are essential to keep the fingerprint recognition system effective.

These extraneous features are reduced by using empirically determined thresholds. For instances a bifurcation having a branch that is much shorter than an empirically determined short isolated line is eliminated because this line is likely to be a spur. Two endings that are closely opposing are eliminated because these are likely to be on the same ridge that has been broken due to a scar or noise or a dry finger condition that results in discontinuous ridges. Endings at the boundary of the fingerprint are eliminated because they are not true endings but rather the extent of the fingerprint in contact with the capture device.

Seven types of False Minutia re specified in following diagrams:

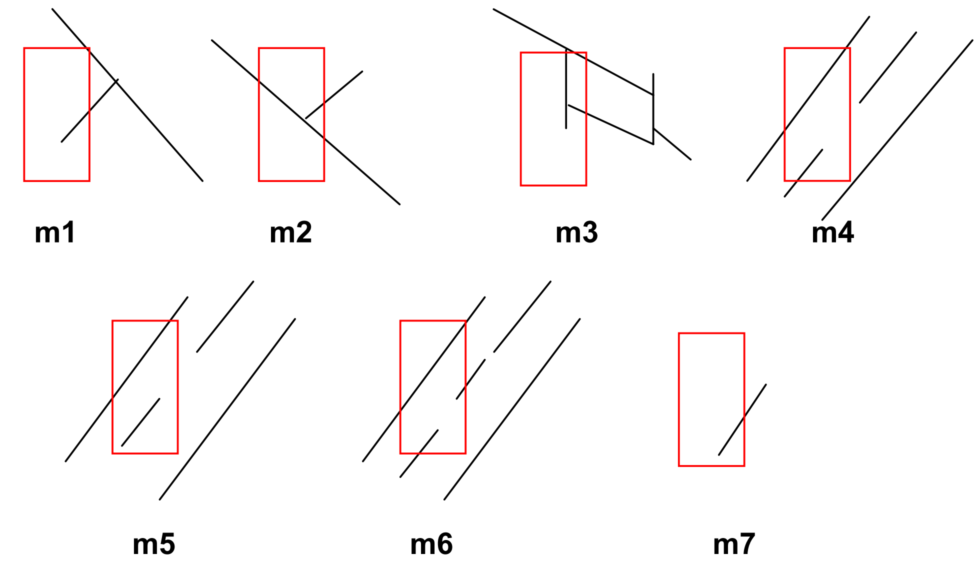


Fig 6.1.1: False Minutia Structures. **m1** is a spike piercing into a valley. In the **m2** case a spike falsely connects two ridges. **m3** has two near bifurcations located in the same ridge. The two ridge broken points in the **m4** case have nearly the same orientation and a short distance. **m5** is alike the m4 case with the exception that one part of the broken ridge is so short that another termination is generated. **m6** extends the m4 case but with the extra property that a third ridge is found in the middle of the two parts of the broken ridge. **m7** has only one short ridge found in the threshold window.

Procedures in Removing False Minutia applied in this Thesis are [3]:

1. If the distance between one bifurcation and one termination was less than '*D'* and the two minutiae were in the same ridge (case-m1). Then both of them were removed. Where '*D'* is the average inter-ridge width representing the average distance between two parallel neighboring ridges.

2. If the distance between two bifurcations was less than '*D'* and they were in the same ridge, the two bifurcations were removed. (cases- m2, m3).

3. If two terminations were within a distance '*D'* and their directions were coincident with a small angle variation and besides no any other termination was located between the two terminations. Then the two terminations were removed considered as false minutia which can be derived from a broken ridge. (cases- m4, m5, m6).

4. If two terminations were located in a short ridge with length less than '*D'*, they were removed. (case-m7).

Fig 6.1.2 and Fig 6.1.3 shows the fingerprint image after false minutia removal.

This procedure in removing false minutia has two advantages. Firstly, the ridge *ID* is used to distinguish minutia and the seven types of false minutia are strictly defined. Secondly, the order of removal procedure is well considered to reduce computational complexity. Like, the procedure-3 solves the m4, m5 and m6 cases in single check routine. And after procedure-3, the number of false minutia satisfying the m7 case is significantly reduced.

But in low quality fingerprint images, the minutia extraction is process may introduce a large number of spurious minutia and the system may not be able to detect all the true minutiae. In this case a quality-checking algorithm can be used to acquire and insert only good quality fingerprint images into the database. A quality check is generally performed to ensure that acquired sample can be reliably processed by successive stages. [1]

The result of the feature extraction stage is called '*Minutia Template',* which is a list of minutiae with accompanying attribute values.

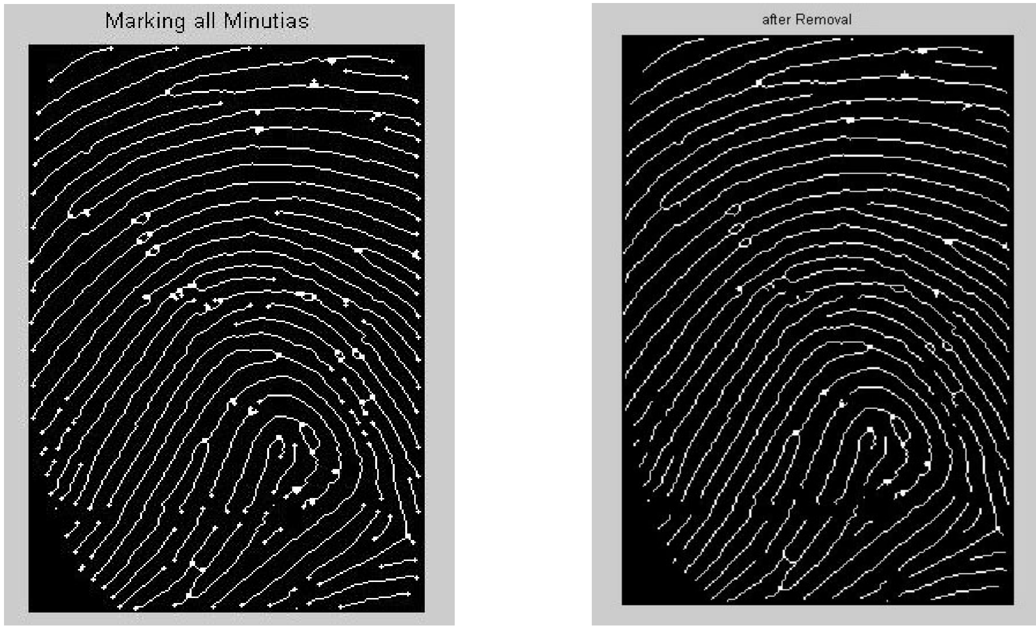


Fig 6.1.2: Fingerprint Image Marking All Bifurcations and Terminations (Left Side); after removing false Bifurcations and Terminations (Right Side)

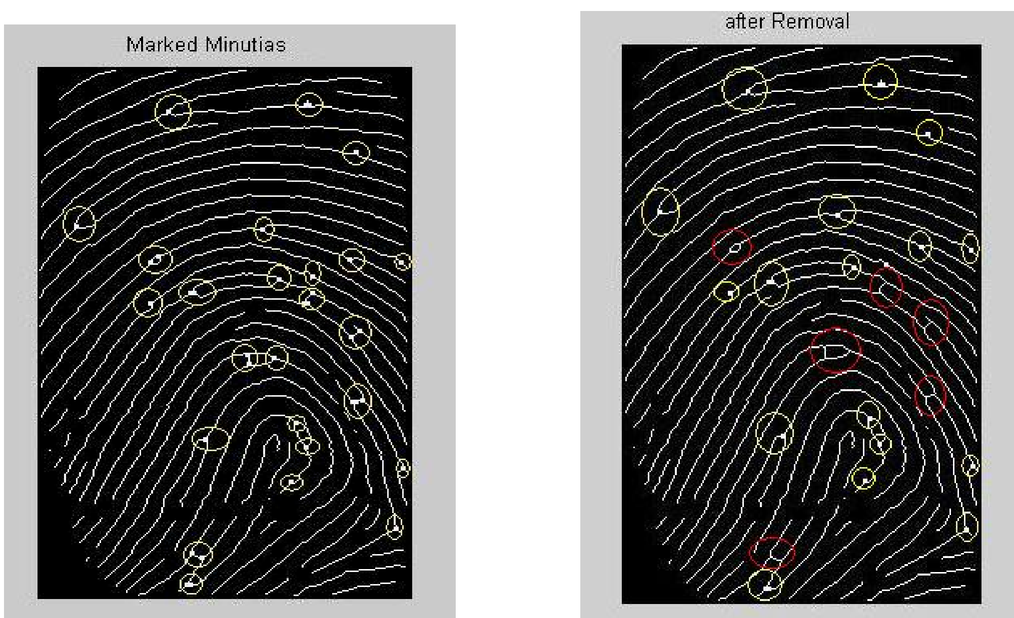


Fig 6.1.3: Fingerprint Image Marking All Bifurcations (Left Side, Yellow circle) after removing false Bifurcations (Right Side, Red circle)

After removal of the false minutiae, the path for each real minutia was calculated, which is shown in [Fig 6.1.4]

Fig 6.1.4: Fingerprint Image after removing false Bifurcations (Left Side), Showing the Path of the Minutiae (Right Side)

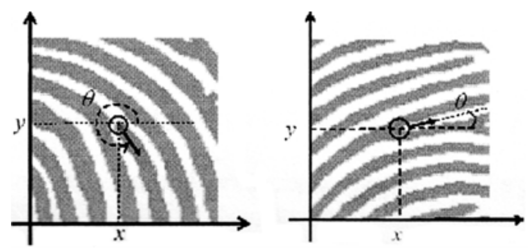
6.2 Unify Terminations and Bifurcations:

Reliably matching fingerprint images is an extremely difficult problem, mainly due to the large variability in different impressions of the same finger (i.e., large Intra-Class variations). The main factors responsible for the Intra-Class variations are: displacement, rotation, partial overlap, non-linear distortion, variable pressure, changing skin condition, noise and feature extraction errors. These can easily change one type of minutia in to the other hand also fingerprint from the same finger may sometimes look quite different whereas fingerprints from different fingers may appear quite similar. [1]

So the Unification representation for both termination and bifurcation is adopted, that's why each minutia is completely characterized by the following parameters at last: i) x-coordinate, y-coordinate and iii) Orientation. [2]

The minutia orientation is defined as the direction of the underlying ridge at the minutia location

.



(a) (b)

Fig 6.2.1: (a) A Ridge Ending Minutia: (x, y) are the minutia coordinates; θ is the minutia's Orientation; (b) A Ridge Bifurcation Minutia: (x,y) are the minutia coordinates; θ is the minutia's Orientation [2]

As all three ridges deriving from the bifurcation point have their own direction, the orientation calculation for a bifurcation need to be considered specially. The method that has applied in this thesis is; at first break a bifurcation in to three terminations. These three new terminations are the three neighbor pixels of the bifurcation and each of the three ridges connected to the bifurcation. Tracking a ridge segment which starting point is the termination and length is 'D'. Sum up all x-coordinates of points in the ridge segment. Similar way the above summation was divided by '*D'* to get ***'sx'*** and ***'sy'.*** [3]

Get the direction from: atan ((sy-sx)/ (sx-tx))

Where, (tx, ty) are the orientation of each termination.

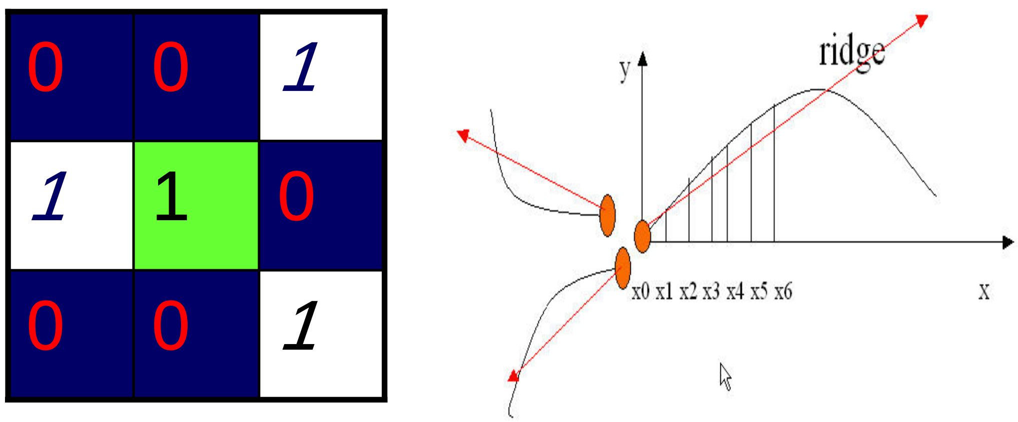


Fig 6.2.2: A Bifurcation to three Terminations.

Three neighbors become Terminations (Left)

Each Termination has own orientation (Right)

7.0 MINUTIA MATCH

7.1 Match Period:

Comparing between the set of minutia of two fingerprints, the Minutia match algorithm determines whether the two minutia sets are from the same finger or not. An alignment -based match algorithm includes two consecutive stages: *i)* ***Alignment Stage*** *and* ***ii) Match Stage***

7.1.1 Alignment Stage:

Aligning the two fingerprints is a mandatory step in order to maximize the number of matching minutiae. Correctly aligning two fingerprints certainly requires *'displacement'* (in x and y) and '*rotation'* (θ) to be recovered and likely involves other geometrical transformations such as 'scale' has to be considered when the resolution of the two fingerprints may vary (e.g., the two fingerprint images have been taken by scanners operating at different resolutions) [1]

Choosing two minutia as a reference minutia pair and then setting the k-th, minutia as origin and align its direction to zero (along x) and then accommodate all other ridge points connecting to the minutia to the new coordinate system If the similarity score of the ridges is larger than a threshold then accommodating all other minutia points in the fingerprint to new origin and two fingerprints are aligned for conducting matching for all minutiae.

The Alignment stage can be accomplished in to in-between two steps. For each minutia the associated ridges are represented as a series of x-coordinates (x_1, x_2, x_3, …… x_n) of the points on that ridge. A point is sampled per ridge length 'L' 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***'

The similarity of correlating the two ridges was derived from the following formula:

$$S = \sum^{m}_{i=0} x_i X_i / [\sum^{m}_{i=0} x_i^2 X_i^2]\ ^{\wedge}0.5$$

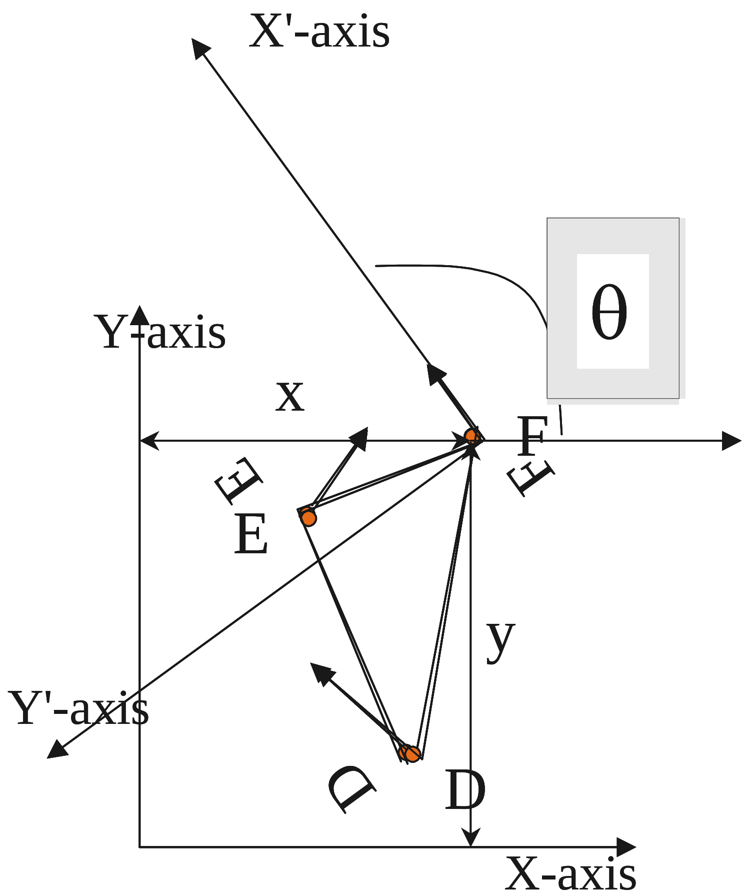
Where ***(xi~xn)*** is a set of minutia for one fingerprint image and ***(Xi~Xn)*** is a set of minutia for another fingerprint image who are going to be compared. For both 'n' and 'N' value 'm' is one of the minimal.

All the minutiae of the fingerprint images were translated and rotated according to the following formula with respect to the reference minutia:

$$\begin{bmatrix} (\text{xi\_new}) \\ (\text{yi\_new}) \\ (\theta\text{i\_new}) \end{bmatrix} = \begin{pmatrix} \cos\theta - \sin\theta & 0 \\ \sin\theta \quad \cos\theta & 0 \\ 0 \qquad 0 & 1 \end{pmatrix} * \begin{pmatrix} \text{xi} - \text{X} \\ \text{yi} - \text{Y} \\ \theta\text{i} - \theta \end{pmatrix}$$

In this formula, (x, y, θ) is the parameters of the reference minutia.

The following diagram illustrates the effect of translation and rotation:



The new coordinate system is originated at minutia F and the new x-axis is coinciding with the direction of minutia F.

In this method the rotation angle was calculated by tracing a short ridge start from the minutia with length *'D'*. On the other hand transformation of each minutia was according to its own reference minutia and matching was done in unified x-y coordinate which lessen the computational complexity. [1][3]

7.1. 2 Match Stage:

After obtaining two set of transformed minutia points, matching algorithm was applied to count the matched minutia pairs by assuming that two minutiae were nearly same position and identical direction.

Matching fingerprint images is a complicated problem, mainly due to their large inconsistency in unusual impressions of the same finger. Hence, the matching algorithm should be expandable.

The matching algorithm was placing a rectangular bounding box of width and height equal to 20 around each template minutia. If the minutia within the box has small direction (pi/3) variation then they regarded as matched minutia pair. Otherwise minutia within the template image has no matched or has only one corresponding minutia.

The final matched ratio for two fingerprints were calculated dividing the total number matched pair over the number of minutia of the template fingerprint.
The score is ***'100*ratio'*** and ranges from 0 to 100. If the score is larger than a pre-specified threshold value (60) than the two fingerprint images will be considered are from the same finger.

8.0 Performance Measurement

Two indexes are well accepted to determine the performance of a Fingerprint recognition system: one is False Rejection Rate (FRR) and the other is False Accept Rate (FAR). [2][3][5]

- **False Rejection Rate (FRR):**

  The probability that the system incorrectly declares failure of match between the input pattern and the matching template in the database is known as False Rejection Rate (FRR) or False Non-match Rate (FNMR). It measures the percent of valid inputs being rejected.

- **False Accept Rate (FAR):**

The probability that the system incorrectly declares a successful match between the input pattern and a non-matching pattern in the database is known as False Accept Rate (FAR) or False Match Rate (FMR). It measures the percent of invalid matches.

The other indexes for performance Measurements are stated bellow [5]:

- **Equal Error Rate (ERR):**

The rates at which both accept and reject errors are equal. The lower the ERR, the more accurate the system is considered to be.

- **Failure to Enroll Rate (FTE or FER):**

  The percentage of data input is considered invalid and fails to input in to the system. Failure to enroll happens when the data obtained by the sensor are considered invalid or poor quality.

- **Failure to Capture Rate (FTC):**

  The probability that the system fails to detect a biometric characteristic, when it is presented correctly within the Automatic system.

- **Template Capacity:**
  The maximum numbers of sets of data which can be input in to the system.

8.1 Experimentation Results

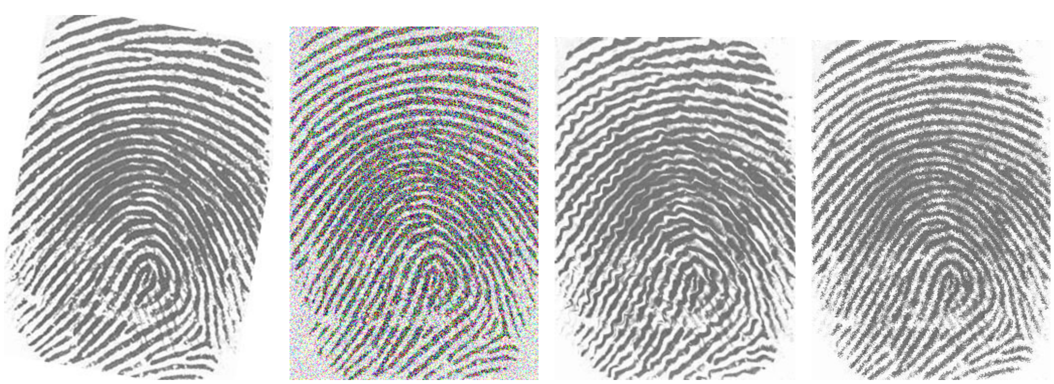
8.1.1 Evaluation for Changed Images:

After all the necessary steps described above, to check whether the system is working properly or not, exactly two similar fingerprint images were compared. The match result was 100% which proves that the system is working in the approved manner.

As biometric recognition works on the principle of a threshold, so now the job comes to settle on a Threshold value for this system.

A *Threshold* is a predetermined number which establishes the degree of correlation necessary for a comparison between a biometric sample and template to be deemed a match. [9]

There are some samples of the changed fingerprint images that were used in this thesis represented in the figure 8.1.1:



(a) (b) (c) (d)

Fig 8.1.1: Changed Fingerprint Images

(a) rotated 3º clock wise; (b) added 50%noise; (c) rippled; (d) diffused

The Match results for 30 changed images:

Table-1: Match results of Changed Images

Image No	Type of Changes	Match results
1	Rotated 3º clock wise	61%
2	Rotated 5º clock wise	64.82%
3	Rotated 10º clock wise	61.67%
4	Rotated 11º clock wise	61.67%
5	Rotated 3º anti-clock wise	37.04%
6	Rotated 10º anti-clock wise	55.56%
7	Rotated 180º clock wise	96.67%
8	added noise 10%	73.33%
9	added noise 15%	55%
10	added noise 20%	95%
11	added noise 25%	65%
12	added noise 30%	68.33%
13	added noise 35%	66.67%
14	added noise 40%	61.67%
15	added noise 45%	66.67%
16	added noise 50%	83.33%
17	added noise 60%	81.667%
18	diffused glow	58.33%
19	added scratches	30%
20	added wave	51.67%
21	Diffused	45%
22	added dust	36.67%
23	Rippled	73.33%
24	Sharpen	70%
25	Custom	75%
26	Photocopy	83.33%

27	Rippled 25%	61.67%
28	sharpen more	68.33%
29	Rotated 90º clock wise	56.67%
30	Twirled	58.33%

It seen from the above analysis that among 30 changed images in 20 cases the match result was above 60% .As in 66.67% cases the match result was found above 60% so the THRESHOLD value for this method has chosen 60%. That means if this system detects 60% similarity between two fingerprint images then it can be decided that those two fingerprints are from the same finger.

8.1.2 Evaluation for Different Images:

For more accurateness 25 totally different fingerprint images were compared in this system.

There are some samples of the different fingerprint images that were used for comparison are resented in the figure 8.2.1:

Fig 8.2.1: Different Fingerprint Images

The Match results for 25 different images:

Table-2: Match results of Different mages

Image no	Fingerprint Image name	Match results
1	finger_03.jpg	58.49%
2	finger_04.jpg	49.05%
3	finger_05.jpg	39.63%
4	finger_06.jpg	56.61%
5	finger_07.jpg	45.28%
6	finger_08.jpg	52%
7	finger_09.jpg	24.53%
8	finger_10.jpg	36%
9	finger_11.jpg	50%
10	finger_12.jpg	43%
11	finger_13.jpg	50%
12	finger_14.jpg	43%
13	Finger_15jpg	41.667%
14	finger_16.jpg	45%
15	finger_17.jpg	38.33%
16	finger_18.jpg	38.33%
17	finger_19.jpg	33.33%
18	finger_20.jpg	41.667%
19	finger_21.jpg	48.33%
20	finger_22.jpg	55%
21	finger_23.jpg	40.0%
22	finger_24.jpg	43..33%
23	finger_25.jpg	56.67%
24	finger_26.jpg	39.33%
25	finger_27.jpg	46.67%

All these 25 fingerprint images were rejected by the system as their entire match results were bellow 60%, that means they did not satisfy the threshold value. Hence, the sensitivity of this technology is close to 100% when applied to different fingerprint images.

All 25 different fingerprint images and 30 changed fingerprint mages that were used for analysis were first converted in to same size and same resolution.

9.0 Conclusion

In this thesis several methods has applied for minutia extraction and minutia matching algorithm which came from wide investigation in to research papers. The results of all subsequent operations depend on the quality of the images. The matching algorithm has large computational complexity and it is vulnerable to spurious minutia but the intention is; the system offering a reasonable speed with a correct answer is much better than a faster system that yields inferior match result.

9.1 Future Work

- Improve the database to compare at least 50 fingerprint images at the same time.
- Adding a Quality-Checking Algorithm to acquire and insert only good quality fingerprint images in to the database.
- Developing a ‘Direct Gray-Scale Minutia Extraction’ to overcome some problems caused by fingerprint Binarization and Thinning.
- Apply ‘Pre-Alignment Minutia Matching’ which is often able to operate with noisy and incomplete data.

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