International Journal of Electronics and Communication Engineering (IJECE)
ISSN(P):2278-9901; ISSN(E): 2278-991X
Vol. 5, Issue 2, Feb - Mar 2016, 29-44

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

FINGERPRINT RECOGNITION SYSTEM

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ABSTRACT

Human fingerprints are rich in details which is known as minutiae, which can be used as identification marks for fingerprint verification. Our term project is to study on fingerprint recognition system based on minutia based matching which is quiet frequently used in various fingerprint algorithms and techniques. The approach of this project involves how the minutia points are extracted from the fingerprint images and after that between two fingerprints we are performing the fingerprint matching. Image enhancement, image segmentation, minutia extraction and minutia matching these stages are the main themes of our project. This project is coded in MATLAB.

KEYWORDS: Scanning of Bio-Metric Fingerprints, Minutia, Fingerprint Verification vs. Identification, Fingerprint Identification Algorithm, Identification for Image Processing, Experimental Result

1. INTRODUCTION

The finger prints are the most important part of human finger. It is experienced from the research that all have their different finger prints and these finger prints are permanent for whole life. So fingerprints have been used for the forensic application and identification for a long time. A finger prints are the most important part of human finger. It is experienced from the research that all have their different finger prints and these finger prints are permanent for whole life. So fingerprints have been used for the forensic application and identification for a long time.

1.1 What is a Fingerprint?

A fingerprint is the composition of many ridges and furrows. Finger prints can't distinguished by their ridges and furrows. It can be distinguished by Minutia, which is some abnormal points on the ridges. Minutia is divided in to two parts such as: termination and bifurcation. Termination is also called ending and bifurcation is also called branch. Again minutia consists of ridges and furrows.

Figure 1.1: Fingerprint Image from a Sensor

However, shown by intensive research on fingerprint recognition, fingerprints are not distinguished by their ridges and furrows, but by features called Minutia, which are some abnormal points on the ridges (Figure 1.2). Among the variety of minutia types reported in literatures, two are mostly significant and in heavy usage:

- Ridge ending - the abrupt end of a ridge
- Ridge bifurcation - a single ridge that divides into two ridges

(a) (b)

Figure 1.2: (a) Two Important Minutia Features (b) Other Minutiae Features

1.2 What is Fingerprint Recognition?

Fingerprint recognition (sometimes referred to as dactyloscopy) is the process of comparing questioned and known fingerprint against another fingerprint to determine if the impressions are from the same finger or palm. It includes two sub-domains: one is fingerprint verification and the other is fingerprint identification (Figure 1.3). In addition, different from the manual approach for fingerprint recognition by experts, the fingerprint recognition here is referred as AFRS (Automatic Fingerprint Recognition System), which is program-based.

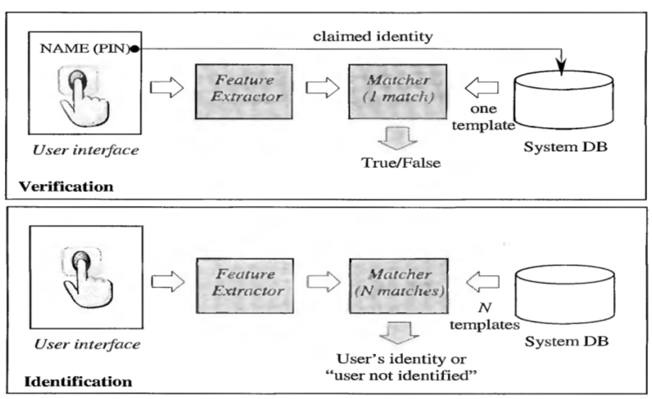


Figure 1.3: Verification vs. Identification

However, in all fingerprint recognition problems, either verification(one to one matching) or identification(one to many matching), the underlining principles of well defined representation of a fingerprint and matching remains the same.

1.3 Fingerprint Matching Techniques

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

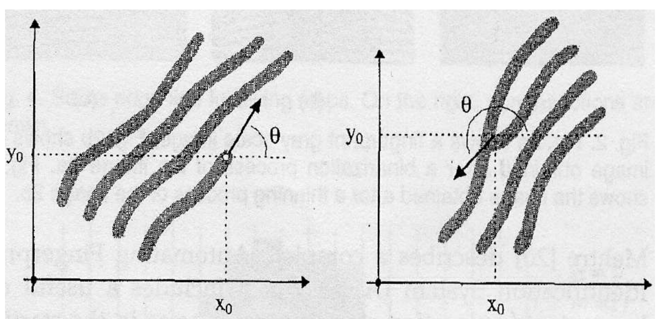
- **Correlation-based matching**: Two fingerprint images are superimposed and the correlation between corresponding pixels is computed for different alignments (e.g. various displacements and rotations).

- **Minutiae-based matching**: This is the most popular and widely used technique, being the basis of the fingerprint comparison made by fingerprint examiners. 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 and the input minutiae sets that results in the maximum number of minutiae pairings
- **Pattern-Based (Or Image-Based) Matching**: Pattern based algorithms compare the basic fingerprint patterns (arch, whorl, and loop) between a previously stored template and a candidate fingerprint. This requires that the images be aligned in the same orientation. To do this, the algorithm finds a central point in the fingerprint image and centers on that. In a pattern-based algorithm, the template contains the type, size, and orientation of patterns within the aligned fingerprint image. The candidate fingerprint image is graphically compared with the template to determine the degree to which they match.

In Our project we have implemented a minutiae based matching technique. This approach has been intensively studied, also is the backbone of the current available fingerprint recognition products.

2. IMPLEMENTATION

We have concentrated our implementation on Minutiae based method. In particular we are interested only in two of the most important minutia features i.e. Ridge Ending and Ridge bifurcation. (Figure 2.1)



(a) (b)

Figure 2.1: (a) Ridge Ending, (b) Ridge Bifurcation

The outline of our approach can be broadly classified into 2 stages - Minutiae Extraction and Minutiae matching. Figure 2.2 illustrates the flow diagram of the same.

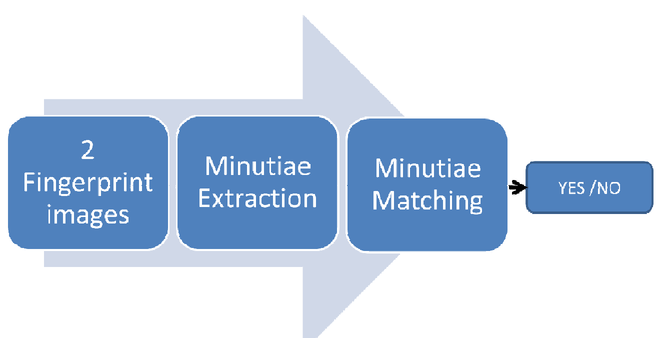


Figure 2.2: System Flow Diagram

The system takes in 2 input fingerprints to be matched and gives a percentage score of the extent of match between the two. Based on the score and threshold match value it can distinguish whether the two fingerprints match or not. The input fingerprints are taken from the database provided by FVC2004 (Fingerprint Verification Competition 2004).

2.1 Design Description

The above system is further classified into various modules and sub-modules as given in Figure 2.3.

Minutia extraction includes Image Enhancement, Image Segmentation and Final Extraction processes while Minutiae matching include Minutiae Alignment and Match processes.

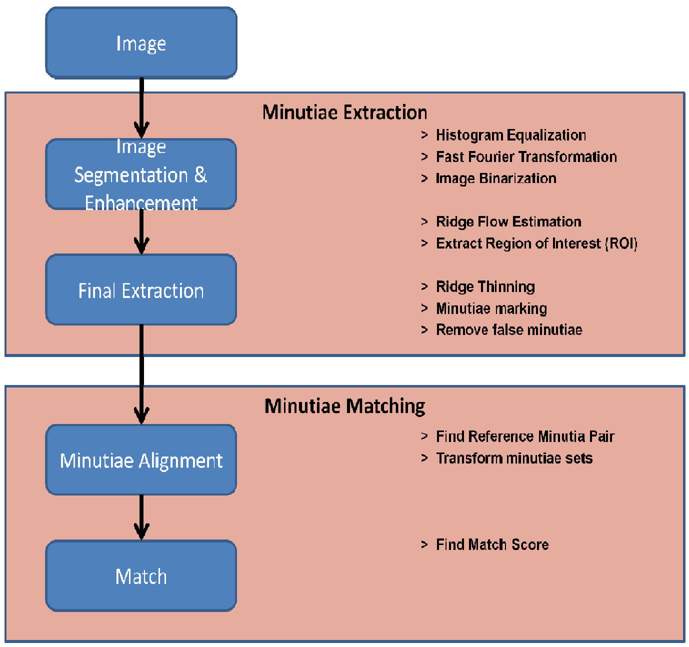


Figure 2.3: Detailed Design Description

Under image enhancement step Histogram Equalization, Fast Fourier Transformation increases the quality of the input image and Image Binarization converts the grey scale image to a binary image.

Then image segmentation is performed which extracts a Region of Interest using Ridge Flow Estimation and MATLAB's morphological functions.

Thereafter the minutia points are extracted in the Final Extraction step by Ridge Thinning, Minutia Marking and Removal of False Minutiae processes.

Using the above Minutia Extraction process we get the Minutiae sets for the two fingerprints to be matched. Minutiae Matching process iteratively 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 to generate a Match Score.

3. MINUTIAE EXTRACTION

As described earlier the Minutiae extraction process includes image enhancement, image segmentation and final Minutiae extraction.

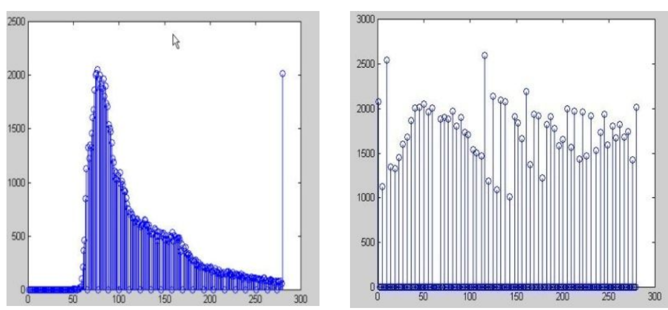
3.1 Fingerprint Image Enhancement

The first step in the minutiae extraction stage is Fingerprint Image enhancement. This is mainly done to improve the image quality and to make it clearer for further operations. Often fingerprint images from various sources lack sufficient contrast and clarity. Hence image enhancement is necessary and a major challenge in all fingerprint techniques to improve the accuracy of matching. It increases the contrast between ridges and furrows and connects the some of the false broken points of ridges due to insufficient amount of ink or poor quality of sensor input.

In our project we have implemented three techniques: Histogram Equalization, Fast Fourier Transformation and Image Binarization.

3.1.1 Histogram Equalization

Histogram equalization is mainly used to increase the pixel value of an image so that the perceptional information also increases. Histogram represents the relative frequency of various types of gray levels in an image. By using this method we can improve the contrast of an image and it is one of the most deserving techniques in image enhancement. The original histogram of a fingerprint image is like a bimodal type after histogram it occupies the range from 0 to 255 and the visualization effect is also increased. The histogram of a fingerprint has bimodal type as shown in the Figure. And the result of the histogram equalization is shown in figure 3.2.



(a) **(b)**

Figure 3.1: (a) Original Histogram, (b) Histogram after Equalization

(a) **(b)**

Figure 3.2(a): Original Image, (b) Enhanced Image after Histogram Equalization

3.1.2 Fast Fourier Transformation

In this method we divide the image into small processing blocks (32 x 32 pixels) and perform the Fourier transform according to equation:

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

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

In order to enhance a specific block by its **dominant frequencies, we multiply the FFT of the** block by its magnitude a set of times. Where the magnitude of the original FFT = abs (F (u, v)) = |F (u, v)|.

So we get the enhanced block according to the equation:

$$g(x,y) = F^{-1}\left\{F(u,v) \times |F(u,v)|^{K}\right\} \tag{2}$$

Where F^{-1}(F (u, v)) is given by:

$$f(x,y) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} F(u,v) \times \exp\left\{j2\pi \times \left(\frac{ux}{M} + \frac{vy}{N}\right)\right\} \tag{3}$$

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

The k in formula (2) is an experimentally determined constant, which we choose k=0.45 to calculate. A high value of k improves the appearance of the ridges by filling up small holes in ridges, but too high value of k can result in false joining of ridges which might lead to a termination become a bifurcation.

Figure 3.3 presents the image after FFT enhancement.

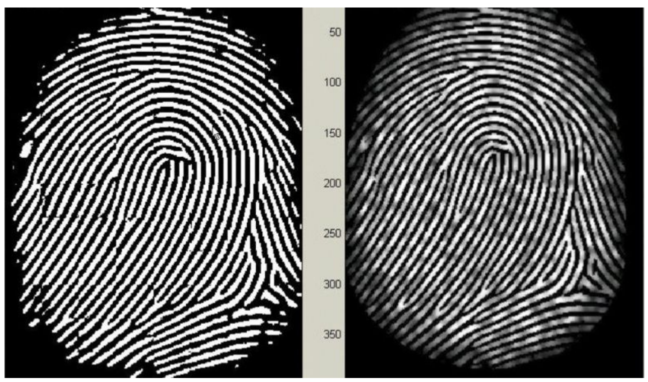
(a) **(b)**

Figure 3.3: (a) Enhanced Image after FFT, (b) Image before FFT

The enhanced image after FFT has the improvements as some falsely broken points on ridges get connected and some spurious connections between ridges get removed.

3.1.3 Image Binarization

In case of image binarization we basically binarize the image by extracting the lightness of the image that is here we extract the brightness and density of the image as a feature amount from the image. When we select a pixel in an image, A sensitivity is added to it and it is subtracted from the Y value of the selected pixel because here we have to set the range of threshold value. Next, when a new pixel is selected again a new threshold value range is set which contains the calculation result and the previous threshold value. Then the pixel is extracted up to the same brightness whatever the selected pixel and the extraction result is displayed. Fingerprint Image Binarization is used to transform the 8-bit Gray fingerprint image to a 1- bit image and here the value for the ridges is 0 where as it is 1 for the furrows. After these operations, the ridges in the fingerprint will be highlighted with black color while furrows will be color with white. To binarize a fingerprint image we basically use a locally adaptive binarization method. To binarize a fingerprint image we basically use a locally adaptive binarization method. The Figure 3.4 shows binarization.



(a) (b)

Figure 3.4: (a) Binarized Image after FFT, (b) Image before binarization

3.2 Fingerprint Image Segmentation

In case of segmentation we basically partition a digital image in to multiple segments that is a set of pixels, it also well known as super pixels. Our aim of the segmentation is to make the image simpler which can be representing very easily and to make the image meaningful so that it will be easy to analyze. Typically image segmentation is used to locate the objects and boundaries like the lines and curves present in an images. Generally Region of Interest (ROI) is very much useful for recognizing each fingerprint image. The image area without effective ridges and furrows holds background information. So the effective ridges and furrows deleted first. Then the remaining effective area is sketched. Because the minutia present in that region are too much confusing with other duplicate minutia which are created when the ridges are out of the sensor.

To extract the region of interest, two steps are followed: Block direction estimation and ROI extraction by Morphological methods.

3.2.1 Block Direction Estimation

Here the fingerprint image is divided into blocks of size 16 x 16 pixels (W x W) after which the block direction of each block is calculated according to the algorithm:

- Calculate the gradient values along x-direction (g_x) and y-direction (g_y) for each pixel of the block. Two Sobel filters are used to fulfill the task.

- For each block, use following formula to get the Least Square approximation of the block direction.

$$tan2\beta = \frac{2\sum\sum(g_x * g_y)}{\sum\sum(g_x^2 - g_y^2)}$$

For all the pixels in each blockThe formula is easy to understand by regarding gradient values along x-direction and y-direction as cosine value and sine value. So the tangent value of the block direction is estimated nearly the same as the way illustrated by the following formula.

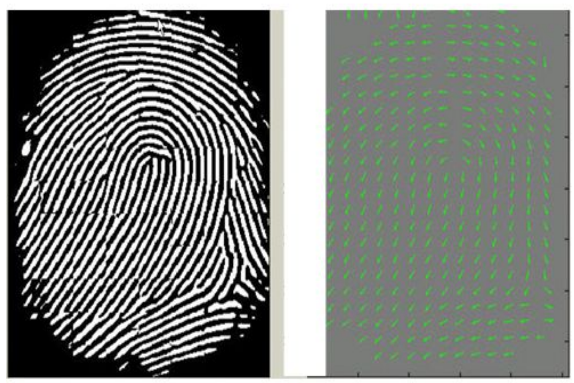
$$tan2\theta = \frac{2sin\theta cos\theta}{cos^2\theta - sin^2\theta}$$

After finished with the estimation of each block direction, those blocks without significant information on ridges and furrows are discarded based on the following formulas:

$$E = \frac{2\sum\sum(g_x * g_y) + \sum\sum(g_x^2 - g_y^2)}{W * W * \sum\sum(g_x^2 + g_y^2)}$$

For each block, if its certainty level E is below a threshold, then the block is regarded as a background block.

The direction map is shown in the following diagram (Figure 3.5).



(a) (b)

Figure 3.4: (a) Binarized Image, (b) Direction map of image

3.2.2 ROI Extraction by Morphological Operations

ROI extraction is done using two Morphological operations called OPEN and CLOSE. The OPEN operation can expand images and remove peaks introduced by background noise (Figure 3.6). The ‘CLOSE’ operation can shrink images and eliminate small cavities (Figure 3.7).

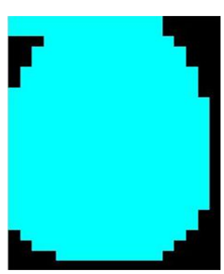


Figure 3.5: Original Image Areas

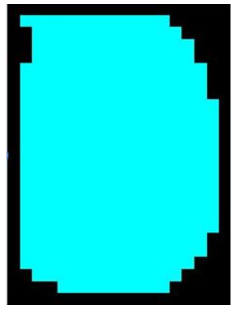


Figure 3.6: After Close

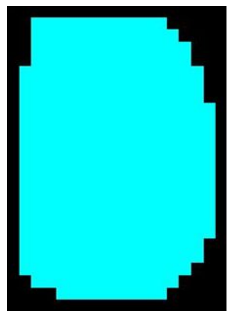


Figure 3.7: After Open

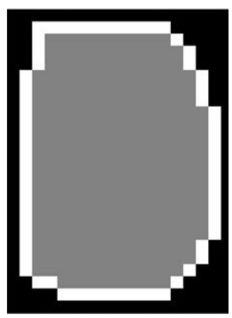


Figure 3.8: Final ROI

Figure 3.8 show the final ROI of the fingerprint which is the bound area after subtraction of the closed area from the opened area. Then the leftmost, rightmost, uppermost and bottommost blocks out of the bound area are discarded.

3.3 Final Minutiae Extraction

Now that we have enhanced the image and segmented the required area, the job of minutiae extraction closes down to four operations: Ridge Thinning, Minutiae Marking, False Minutiae Removal and Minutiae Representation.

3.3.1 Ridge Thinning

The ridge thinning process is used to eliminate the redundant pixels of ridges till the ridges are just up to one pixel wide. This is done by using the following MATLAB‟s thinning function. Bwmorph (binaryImage,' thin', Inf)

Then the thinned image is filtered by using the following three MATLAB's functions. This is used to remove some H breaks, isolated points and spikes.

Bwmorph (binaryImage, ‟ hbreak', k)

Bwmorph (binaryImage, "clean', k)

bwmorph (binary Image," spur', k)

(a) (b)

Figure 3.9: (a) Image before, (b) Image after Thinning

3.3.2 Minutiae Marking

Minutiae marking are now done using templates for each 3 x 3 pixel window as follows.

If the central pixel is 1 and has exactly 3 one-value neighbors, then the central pixel is a ridge branch (Figure 3.10).

0	1	0
0	1	0
1	0	1

Figure 3.10

If the central pixel is 1 and has only 1 one-value neighbor, then the central pixel is a ridge ending (Figure 3.11).

0	0	0
0	1	0
0	0	1

Figure 3.11

There is one case where a general branch may be triple counted (Figure 3.12). Suppose both the uppermost pixel with value 1 and the rightmost pixel with value 1 have another neighbor outside the 3x3 window due to some left over spikes, so the two pixels will be marked as branches too.

0	1	0
0	1	1
1	0	0

Figure 3.12

3.3.3 False Minutiae Removal Technique

At this stage false ridge breaks due to insufficient amount of ink & ridge cross connections due to over inking are not totally eliminated. Also some of the earlier methods introduce some spurious minutia points in the image. So to keep the recognition system consistent these false minutiae need to be removed.

Here we first calculate the inter ridge distance D which is the average distance between two neighboring ridges. For this scan each row to calculate the inter ridge distance using the formula:

$$Inter\ ridge\ distance = \frac{sum\ all\ pixels\ with\ value\ 1}{row\ length}$$

Finally an averaged value over all rows gives D.

All we label all thinned ridges in the fingerprint image with a unique ID for further operation using a MATLAB morphological operation BWLABEL.

Now the following 7 types of false minutia points are removed using these steps (Figure 3.13).

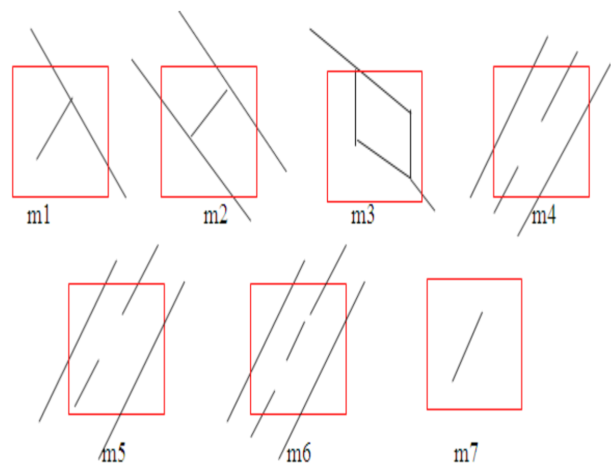


Figure 3.13

- If d(bifurcation, termination) < D & the 2 minutia are in the same ridge then remove both of them (case m1)
- If d(bifurcation, bifurcation) < D & the 2 minutia are in the same ridge them remove both of them (case m2, m3)
- If d(termination, termination) ≈ D & the their directions are coincident with a small angle variation & no any other termination is located between the two terminations then remove both of them (case m4, m5, m6)
- If d(termination, termination) < D & the 2 minutia are in the same ridge then remove both of them (case m7)

Where d(X, Y) is the distance between 2 minutia points

3.3.4 Minutiae Representation

Finally after extracting valid minutia points from the fingerprint they need to be stored in some form of representation common for both ridge ending and bifurcation.

So each minutia is completely characterized by the following parameters 1) x-coordinate, 2) y-coordinate, 3) orientation and 4) ridge associated with it (Figure 3.14)

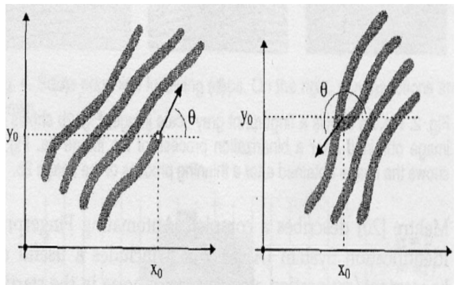


Figure 3.14

Get the direction from: $\tan^{-1}\frac{sy-ty}{sx-tx}$

Results after the minutia extraction stage (Figure 3.15-3.17)

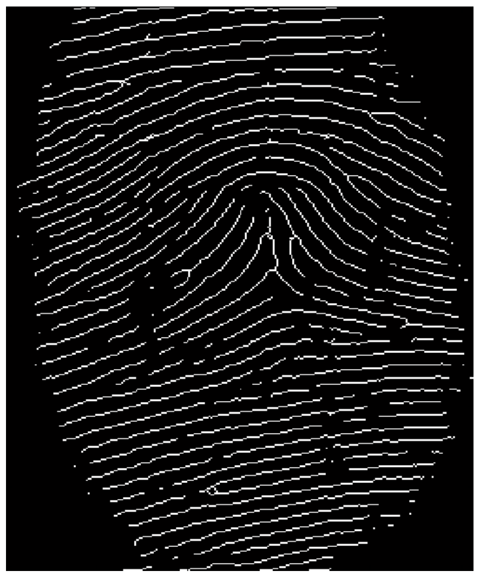


Figure 3.15: Thinned Image

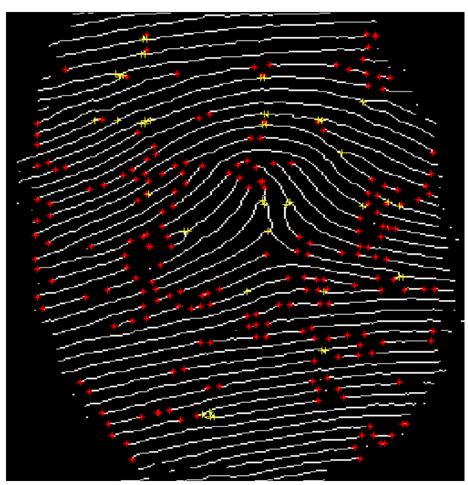


Figure 3.16: Minutiae after Marking

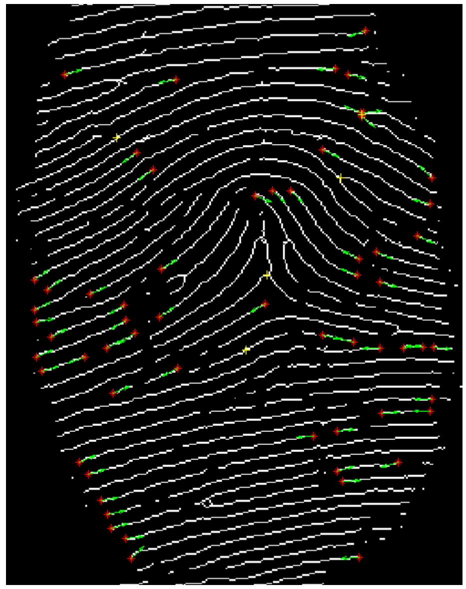


Figure 3.17: Real Minutiae after False Removal

4. MINUTIAE MATCHING

After testing the set of minutia set of points of two finger print image we perform Minutiae Matching to check whether they belong to the same person or not. It includes two consecutive stages:

- alignment stage
- match stage

4.1 Minutiae Alignment

Let I_1 & I_2 be the two minutiae sets given by,

$$I_1 = \{m_1, m_2 \ldots m_M\} \text{ where } m_i = (x_i, y_i, \theta_i)$$

$$I_2 = \{m'_1, m'_2 \ldots m'_N\} \text{ where } m'_i = (x'_i, y'_i, \theta'_i)$$

Now we choose one minutia from each set to find the ridge correlation factor between them. The ridge associated with each minutia is represented as a series of x-coordinates ($x_1, x_2 \ldots x_n$) of the points on the 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.

So the similarity of correlating the two ridges is derived from:

$$S = \sqrt{\frac{\sum_{i=0}^{m} xiXi}{\sum_{i=0}^{m} xi^2 Xi^2}}$$

Where ($x_i \ldots x_n$) and ($X_i \ldots X_n$) are the set of x-coordinates for each of the 2 minutia chosen. And m is minimal one of the n and N value. If the similarity score is larger than 0.8, then go to step 2, otherwise continue to match the next pair of ridges.

2. The approach is to transform each set according to its own reference minutia and then do match in a unified x-y coordinate.

Let M (x, y, θ) be reference minutia found from step 1(say from I_1). For each fingerprint, translate and rotate all other minutiae $(xi, yi, \theta i)$ with respect to the M according to the following formula:

$$\begin{pmatrix} xi\_new \\ yi\_new \\ \theta i\_new \end{pmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} xi - x \\ yi - y \\ \theta i - \theta \end{bmatrix}$$

The new coordinate system is originated at reference minutia M and the new x-axis is coincident with the direction of minutia M. No scaling effect is taken into account by assuming two fingerprints from the same finger have nearly the same size.

So we get transformed sets of minutiae I_1' & I_2'

4.2 Minutiae Match

An elastic string (x, y, θ) match algorithm is used to find number of matched minutia pairs among I_1' & I_2'.

According to the elastic string match algorithm minutia m_i in I_1' and a minutia m_j in I_2' are considered "matching," if the spatial distance (sd) between them is smaller than a given tolerance r_0 and the direction difference (dd) between them is smaller than an angular tolerance Θ_0.

$$\text{sd} = \sqrt{(xi - xj)^2 + (yi - yj)^2} \leq r_0$$

$$\text{dd} = \min\ (|\theta i - \theta j|, 360 - |\theta i - \theta j|) \leq \Theta_0$$

Let mm (.) be an indicator function that returns 1 in the case where the minutiae m_i and m_j match according to above equations.

$$\text{Mm}\ (m_i, m_j) = \begin{cases} 1, & sd(m_i, m_j) \leq r_0 \text{ and } dd(m_i, m_j) \leq \theta_0 \\ 0, & otherwise \end{cases}$$

Now the total number of matched minutiae pair given by,

$$\text{Num (matched minutiae)} = \sum \text{mm}(m_i, m_j)$$

And final match score is given by,

$$\text{Match Score} = \frac{num\ (matched\ minutiae)}{\max\ (num\ of\ minutiae\ in\ I_1, I_2)}$$

5. EXPERIMENTAL RESULTS

Performance Evaluation Index

There are two types" performance evaluation indexes to determine the performance of a fingerprint recognition system such as:-

False Rejection Rate (FRR): Sometimes the biometric security system may incorrectly reject an access attempt by an authorized user. To measure these types of incidents FAR is basically used. A system's FRR basically states the ratio between the number of false rejections and the number of identification attempts.

FRR

(%) FRR= (FR/N)*100

FR=number of incidents of false rejections

N= number of samples

False Acceptance Rate (FAR): Sometimes the biometric security system may incorrectly accept an access attempt of an unauthorized user. To measure these types of incidents FAR is basically used. A system's FAR basically states the ratio between the number of false acceptances and the number of identification attempts.

FAR

(%) FAR= (FA/N)*100

FA= number of incidents of false acceptance

N=total number of samples

The false acceptance rate and the false reject rate depends upon the quality of the image whether the quality is good or bad

6. CONCLUSIONS

The above implementation was really an effort to understand how the Fingerprint Recognition is used in many applications like biometric measurements, solving crime investigation and also in security systems. From minutiae extraction to minutiae matching all stages are included in this implementation which generates a match score. Various standard techniques are used in the intermediate stages of processing.

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