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Overview of Fingerprint Image Enhancement & Minutia Extraction

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Abstract : Minutia points are the local discontinuities in the fingerprint pattern.There are many types of minutia identified.However two types of minutia viz.,terminations and bifurcations are considered for automatic fingerprint identification purposes. Accurate extraction of minutia points is the first step towards developing a reliable fingerprint recognition system. However a fingerprint image may not always be well captured and may contain noise which hinders the clarity of the ridge and valley structures. This could be due to variations in skin structure such as scars , and certain impression conditions such as humidity, dirt, and non-uniform contact with the fingerprint capturing device . Image enhancement techniques are therefore required and are often employed to reduce the noise and enhance the definition of ridges against valleys. This paper is an overview of the image enhancement techniques employed specifically for fingerprint image enhancement.

Key Words : Fingerprint biometric, minutia , image preprocessing , image post processing.

1.INTRODUCTION

Automatic fingerprint identification is the most popularly employed biometric identification today. The popularity of fingerprint biometric is due to the fact that it is easier to obtain public consent for the use of fingerprint biometric as fingerprint identification has been in use by law enforcement agencies for as many as 50 years by now. Secondly the equipment for fingerprint identification is less expensive compared to iris or retinal scans. Also fingerprint biometric is less intrusive for the user and needs minimum contact area compared to iris, retina and palm print biometrics. All these factors contribute to a lion's share of 55% market for fingerprint biometrics.

1.1 Physical Features of a finger : Fingerprints are the tiny ridge and valley patterns on the tip of each finger. They form from pressure on a baby's tiny, developing fingers in the womb. No two people have been found to have the same fingerprints. Each ridge contains pores, which are attached to sweat glands under the skin. Fingerprints are left on smooth surfaces like glass or paper ,because of this sweat.

The ridges of fingerprints have been classified to form three patterns called loops, whorls and arches . A **Loop** begins on one side of the finger , curves around or upward, and exits from the other side. There are two types of loops - **Radial loops** which slope toward the thumb and **ulnar loops** which slope towards the little finger. **Whorls** form a circular or spiral pattern. **Arches** slope upward and then down, like very narrow mountains.

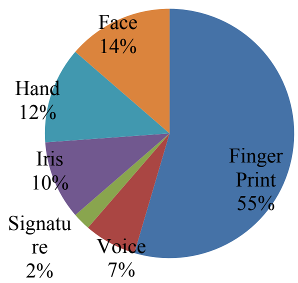

Fig 1 : Market share of various biometrics

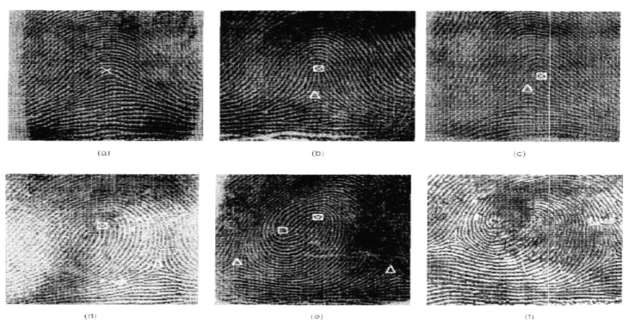

Fig 2 : Gray level fingerprint images of different types of patterns with core (□) and delta (Δ) points: (a) arch; (b) tented arch; (c) right loop; (d) left loop; (e) whorl; (f) twin loop (Ratha et al., 1996) [15]

The ridges and valleys in a fingerprint alternate, flowing in a local constant direction. Eighteen different types of fingerprint features have been enumerated by Federal Bureau of Investigation, 1984. Further, a total of 150 different local ridge characteristics have been identified by Kawagoe & Tojo, 1984. Collectively, these features are called *minutiae.*

The pattern , shape, size and number of lines in these fingerprint patterns along with **minutiae** distinguish one fingerprint from another.

1.2 The fingerprint database template : There are two approaches to creating the fingerprint database template .

1.2.1 Image based approach : This approach , uses image-based methods and tries to match fingerprints based on the global features of a whole fingerprint image[3][4]. It is an advanced and newly emerging method for fingerprint recognition.

1.2.2 Minutia based approach : The more popular method is called minutia-based, and represents the fingerprint by its local features. This approach has been intensively studied and forms the basis of most of the current fingerprint recognition products. This is also the method followed in the manual process of fingerprint matching. The fingerprint has been observed to consist of a number of distinguishable features called minutia which are as follows :

a) Core : It is approximately the centre of a fingerprint .Core is located at the point where the innermost recurve begins and curves to exit the same way they came in.
b) Delta : Deltas are located between two diverging type lines and are located on or directly in front of their point of divergence. Among the three fingerprint patterns viz ., whorls , arches and loops , arches do not have core or delta.
c) Ridges and valleys: Ridges are the upper skin layer segments and valleys are lower segments of a fingerprint.
d) Dots : Dots are tiny ridges that are nearly round.
e) Islands : Islands are short ridges.
f) Ponds and lakes : These are open places with a single ridge.
g) Spurs : These are points that break off a main ridge.
h) Bifurcations : These are ridge splits.
i) Crossovers : These are points that connect two ridges.

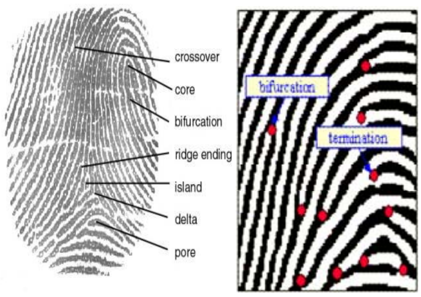

Fig 3 : Minutia features of a fingerprint[2]

Out of these the two most prominent local ridge characteristics are: 1) ridge ending and, 2) ridge bifurcation. A ridge ending is defined as the point where a ridge ends abruptly. A ridge bifurcation is defined as the point where a ridge forks or diverges into branch ridges. Most of the fingerprint extraction and matching techniques restrict the set of minutia features to *ridge endings* and *ridge bifurcations*. A good quality fingerprint typically contains about 40–100 minutiae.

Fingerprints are identified to individuals by examining and comparing the ridge characteristics of two different impressions to determine if these characteristics occupy the same relative area and position and if their unit relationship to each other matches.

2. FINGERPRINT IMAGE ENHANCEMENT

The accuracy of fingerprint matching depends upon how accurately the minutiae are detected. Some times the Fingerprint image may be smudged , oily or dirty.This in turn results in improper and/or spurious minutia points .This will result in inaccurate results. Hence it is very important to apply corrections to the image before confirming the minutia points . This process of improving the quality of the image is called image enhancement. The procedure to enhance the image and read only correct minutia involves following steps

1. Pre-Processing
2. Minutiae extraction
3. Post-Processing

2.1 Preprocessing : The Figure 4 below shows various steps involved in pre-processing.These steps are elaborated in the following sections.

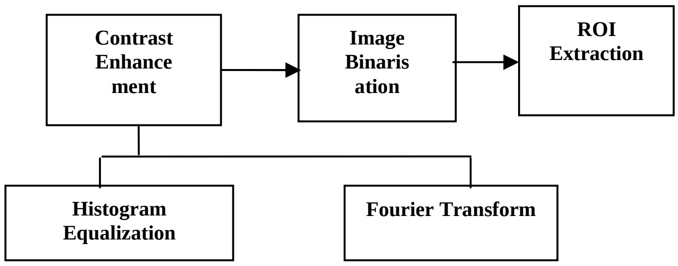

Fig 4 : Steps involved in Preprocessing a fingerprint image

2.1.1Contrast enhancement : Contrast enhancement increases the contrast between ridges and valleys.This step also helps to eliminate noise between ridges and connect the false broken points of ridges. Two methods can be adopted for this purpose which are as follows :

2.1.1.1 Histogram equalization : Image Histogram is a graphical representation of the intensity distribution of an image. It quantifies the number of pixels for each intensity value as shown in Figure 5.

Histogram equalization is a method that improves the contrast in an image.In essence the process stretches out the intensity range. Equalization thus means *mapping* one distribution -the given histogram- to another distribution -a wider and more uniform distribution - of intensity values,This makes the intensity values spread over the whole range. The resulting gray level transform is simply a scaled version of the original image's cumulative histogram. That is, the Gray level transform T is given by $T[i] = (G-1)\ c(i)$, where G is the number of gray levels and c(i) is the normalized cumulative histogram of the original image.

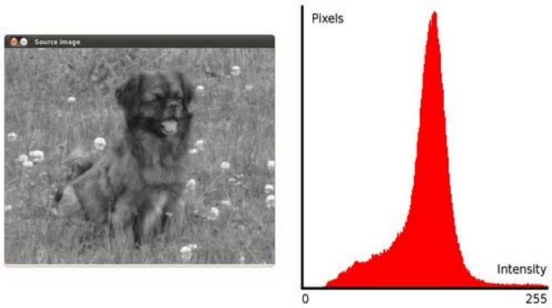

Fig 5 : Histogram distribution of an image

In Fig 5 , the histogram of the image shows the pixels clustered around the middle of the available range of intensities. Histogram Equalization *stretches out* this range. A fingerprint image and its histogram before and after equalization is shown as under in Figure 6 [16].

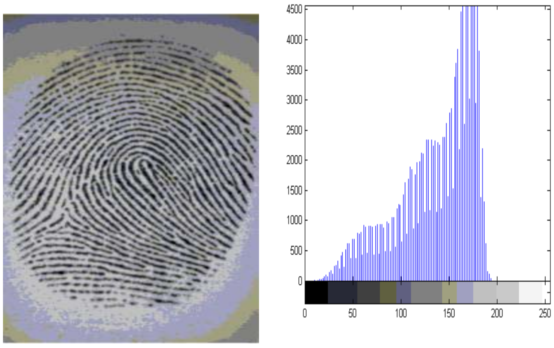

Fig 6 : A fingerprint and corresponding histogram before equalization

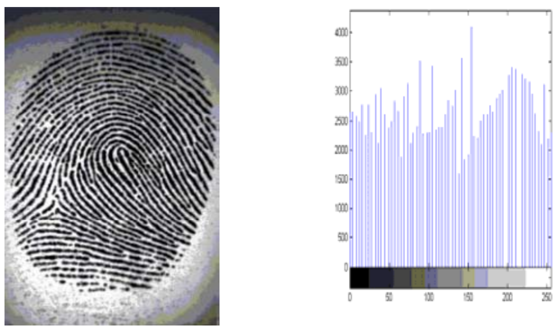

Figure 7 : Fingerprint Image and histogram after equalization

2.1.1.2 Fourier Transform : The Fourier transform is widely used in signal and image processing in particular, for detection of high or low frequencies. Since the ridges pocess the structure of repeated and parallel lines, it is possible to determine the frequency and the ridge orientation using FFT transform. Considering this characteristic, a fingerprint image is divided in blocks of small size (e.g., 32x32). For each block FFT transform is applied , and then multiplied by its power spectrum raised to some value 'k' .Thereafter inverse FFT is applied to the resulting image. The following figure shows the processing sequence[6].

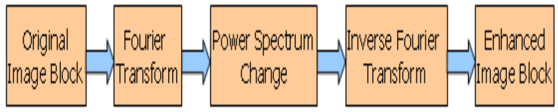

Fig 8 : Steps in the processing of FFT

Generally, the blocks are constructed using overlapped windows, in order to avoid the border effect of FFT.
The Fourier transform itself is performed according to equation below:

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

……………………………(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 is multiplied by its magnitude a set of times, where the magnitude of the original FFT = abs(F(u,v)) = |F(u,v)|. The enhanced block is according to equation

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

…………………….(2)

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

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

…………………………(3)

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

The 'k' in formula (2) is an experimentally determined constant, which can be choosen . 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. Figure 6 illustrates the use of enhancement using FFT transform.

Fig 9 : Original image of Fingerprint and image enhanced by FFT

The enhanced image after FFT has the improvements viz., connecting some falsely broken points on ridges and removing some spurious connections between ridges.

2.1.2 Image Binarization :

Fingerprint Image Binarization transforms the 8-bit Gray fingerprint image to a 1-bit image with 0-value for ridges and 1-value for furrows. After the operation, ridges in the fingerprint are highlighted with black color while furrows are white. Global thresholding sets all pixels above a defined value to white and the rest of the pixels to black in the image[8].A locally adaptive binarization method transforms a pixel value to 1 if the value is larger than the mean intensity value of the current block (16x16) to which the pixel belongs and to 0 if the value is smaller than the mean intensity value of the current block.

Fig. 10:. the Fingerprint image after adaptive binarization . Binarized image (left) , Enhanced gray image (right)

2.1.3 ROI extraction : 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 discarded since it only holds background information. To extract the ROI, a two-step method is used. The first step is block direction estimation and direction variety check [7], while the second depends on Morphological methods.

3. MINUTIA EXTRACTION

3.1 Fingerprint Ridge thinning : Ridge Thinning is to eliminate the redundant pixels of ridges until the ridges are just one pixel wide. L.C. Jain, U.Halici, I. Hayashi, S.B. Lee and S.Tsutsui used an iterative, parallel thinning algorithm. In each scan of the full fingerprint image, the algorithm marks down redundant pixels in each small image window (3x3) [9]. Finally removes all those marked pixels after several scans. D.Maio and D. Maltoni, use a method which traces along the ridges having maximum gray intensity value. In this method, binarization is implicitly enforced since only pixels with maximum gray intensity value remain[10].

3.2 Minutia marking : Minutiae extraction is done by using the crossing number approach [11]. Crossing number of pixel '*p*' is defined as half the sum of the differences between pairs of adjacent pixels defining the 8-neighborhood of '*p*'. Mathematically

$$\mathrm{Cn}(p) = \frac{1}{2} \sum_{i=1..8} \left(\begin{array}{c} |\mathrm{val}(p_{i\ mod\ 8}) - \\ \mathrm{val}((p_{i-1}| \end{array} \right)$$

Where p_0 to p_7 are the pixels belonging to an ordered sequence of pixels defining the 8-neighborhood of p and *val (p)* is the pixel value.

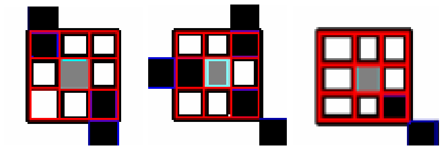

Fig 11: *cn (p)=2*,*cn (p)=3* and *cn (p)=1* representing a nonminutiae region, a bifurcation and a ridge ending [12]

Crossing numbers 1 and 3 correspond to ridge endings and ridge bifurcations respectively. An intermediate ridge point has a crossing number of 2[12].

4. POST PROCESSING

The different types of false minutiae introduced during minutiae extraction are specified in following diagrams:[13]

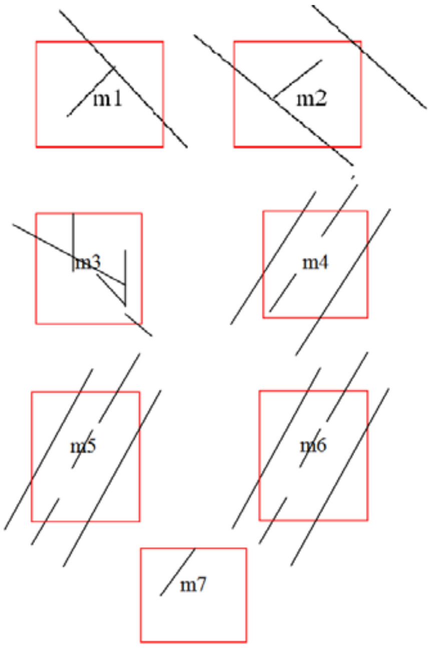

Fig 12: False Minutia Structures.

m1 is a spike piercing into a valley. **m2** is the case where 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.

The procedure to remove false minutia is as follows :

1. If the distance between one bifurcation and one termination is less than D and the two minutia are in the same ridge(m1 case) . Remove both of them. Here D is the average inter-ridge width representing the average distance between two parallel neighboring ridges.

2. If the distance between two bifurcations is less than D and they are in the same ridge, remove the two bifurcations. (m2, m3 cases).
3. If two terminations are within a distance D and their directions are coincident with a small angle variation. And they suffice the condition that no any other termination is located between the two terminations. Then the two terminations are regarded as false minutia derived from a broken ridge and are removed. (case m4,m5, m6).
4. If two terminations are located in a short ridge with length less than D, remove the two terminations (m7).

5. MINUTIA MATCH

Given two sets of minutia of a fingerprint , the minutia match algorithm determines whether the two minutia sets are from the same finger or not. An alignment-based match algorithm [14] can be used for the purpose. It includes two stages ; one is alignment stage and the second is match stage.

5.1 Alignment stage : Given two fingerprint images to be matched, this algorithm chooses any one minutia from each image, calculates the similarity of the two ridges associated with the two referenced minutia points. If the similarity is larger than a threshold, each set of minutia is transformed to a new coordinate system whose origin is at the referenced point and whose x-axis is coincident with the direction of the referenced point.

5.2 Match stage : After getting two set of transformed minutia points, the elastic match algorithm is used to count the matched minutia pairs by assuming that two minutia having nearly the same position and direction are identical.

6.CONCLUSION AND FUTURE SCOPE :

This paper is an effort to give an overview of how fingerprint minutiae are extracted from a fingerprint image. Extracting reliable minutia points is an important step in fingerprint biometry as the resulting match/nonmatch results depend to a large extent on this step. Therefore fingerprint extraction process should be able to overcome foggy, latent and even partial images. It should also be robust against variations in skin structure such as scars , and certain impression conditions such as humidity, dirt, and non-uniform contact with the fingerprint capturing device . In this context further work can be done in improving the contrast enhancement algorithm, algorithm to estimate Region Of Interest , thinning algorithm and algorithm to remove false minutiae.

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