Minutiae Based Fingerprint Matching Techniques

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Abstract—**Fingerprints are unique, permanent and universal. The minutiae of fingerprints of a human have sufficient details. We can use these non-trivial details as identification marks to verify the fingerprints. The purpose of this paper is to investigate and implement the working of minutiae based fingerprint matching system. Minutiae based fingerprint matching is widely used for fingerprint verification. In this method first, Fingerprint image is enhanced using Fast Fourier Transform and converted to binary image for further processing. In second step, image is thinned and minutiae are extracted. Finally, minutiae pairs of two fingerprints are matched to get matching score. This method has the ability to find the similarity between input minutiae sample and the stored minutiae sample without using the tiring investigation. By using the database fingerprints of different people, the performance of the system has been computed.**

I. INTRODUCTION

The fingerprint based identification of individual is the most reliable and comprehensive in comparison to the other biometric techniques. It is usually used in forensic labs to find the footprint of suspects. Also, it is widely used for personal identification [1, 5].

Fingerprints of every person are unique and remain unchanged during whole life. A Fingerprint comprises of curvilinear patterns called ridges. Minutiae are discontinuities in ridges, which are used as feature for identification. Space between two adjacent ridges is termed as valley. According to National Institute of Standards and Technology (NIST), standard representation of a fingerprint is based on minutiae and it includes minutia location and orientation [4].

Two most important minutiae are ridge termination and ridge bifurcation. Ridge termination is a point on the ridge where it terminates. Whereas the point at which a single ridge splits into two ridges is called ridge bifurcation [1]. Fig. 1 illustrates ridge termination and ridge bifurcation.

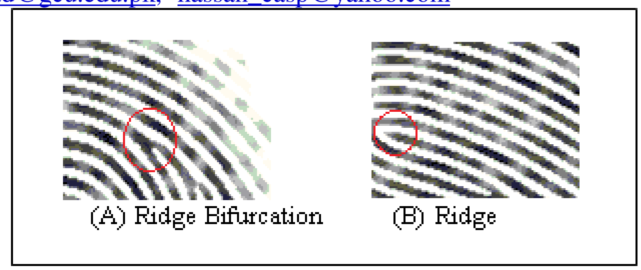

Fig. 1 Ridge bifurcation and Ridge termination

II. FINGERPRINT SYSTEM DESIGNS

We developed two level fingerprint based matching systems.

1. Algorithm level Design
2. System Level Design

Algorithm Level Design (ALD) describes the working of fingerprint matching algorithms. While System Level Design (SLD) is practical level design. This system enrolls given fingerprint into the database and also performs matching of a given fingerprint with database fingerprints. Block diagrams of both Designs are given in Fig. 2 & Fig. 3.

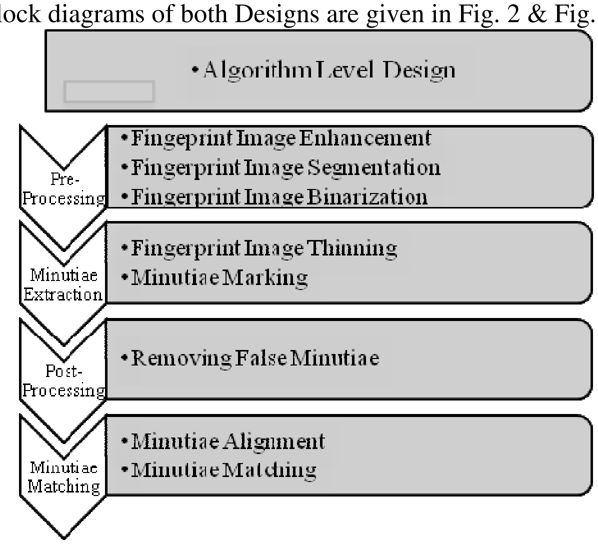

Fig. 2 Algorithm Level Design

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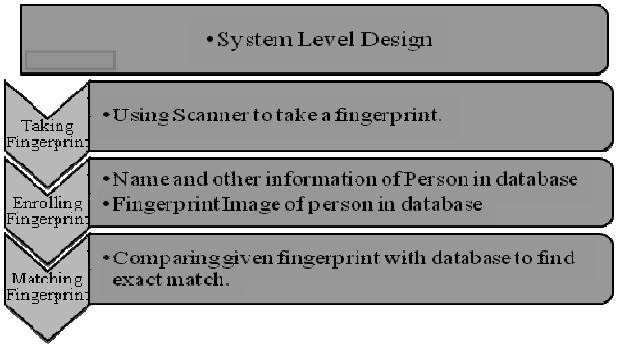

Fig. 3 System Level Design

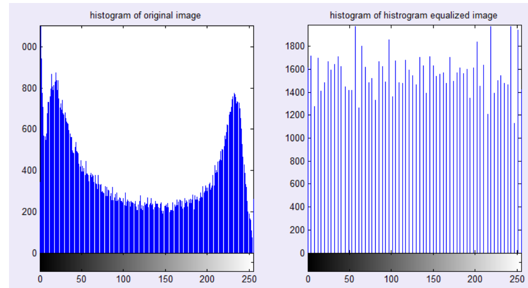

Fig. 5 Histogram of original image on left and equalized image on right.

III. FINGERPRINT IMAGE ENHANCEMENT

The image which is taken by the scanner is noisy, due to different reasons, e.g. it may contain dust particles. Thus, first fingerprint image is enhanced to extract more details. Enhancement techniques differentiate ridges and valleys from each other and join incomplete points of the ridges which are disconnected erroneously. Enhancement is made by Histogram Equalization and Fast Fourier Transform.

A. Enhancement by Histogram Equalization

In Histogram Equalization, we increase the distribution of intensity level of pixels on the input image to get the complete insight of image. For better results, we used method discussed by Greenberg et. al. in [9].

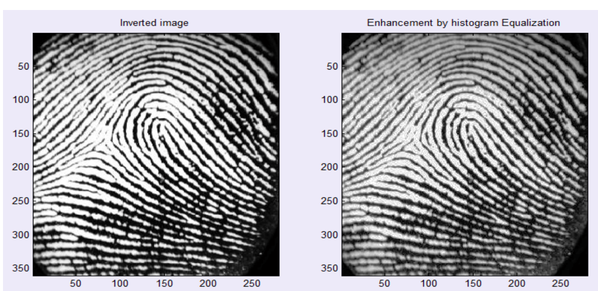

Fig. 4 Original image left and histogram equalized image on right.

The corresponding histograms of these two images are shown in Fig. 5. It can be realized vividly that histogram equalized image has uniform gray level distribution while unequalized image has a deep valley showing uneven distribution of gray levels.

B. Fast Fourier Transform Enhancement

Second stage of image enhancement is using Fourier transform. For this, histogram equalized image is segmented into small blocks (32 by 32 pixels) and then apply Fourier transform on these blocks one by one. Unfortunately, to avoid discontinuities at the edges between adjacent blocks, a large amount of overlap between two neighboring blocks (e.g., 24 pixels) is necessary which significantly increases the enhancement time [11].

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

Where u = 0, 1, 2... 31, v = 0, 1, 2... 31 and M=N=32. To enhance a particular block we multiply, the Fast Fourier Transform of the block by its magnitude k times and take inverse Fourier Transform. The value of k can either be 0.6[6] or 1.40 [10].

$$I(x,y) = F^{-1}\{F(u,v) \times |F(u,v)|^{k}\} \qquad (2)$$

Where I(x, y) is enhanced image. Value of k should not be either too large or too small. By applying FFT, the incorrectly splitted ridges are connected and it may remove the incorrect connections among ridges shown below.

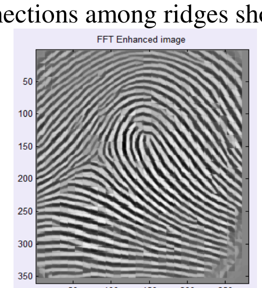

Fig. 6 Fast Fourier Transform enhanced image

IV. FINGERPRINT IMAGE BINARIZATION

To binarize histogram equalized image, divide this image into small blocks of size 16x16 pixels, then calculate the mean of each block. After calculating mean check the value of each pixel in the block. If pixel value is greater than mean value then assign binary 1 to pixel value, else assign 0 to pixel value. Binary 0/black represents valley and binary 1/white represents ridge.

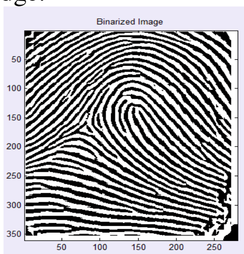

Fig. 7 Binarized image

V. FINGERPRINT IMAGE SEGMENTATION

Removing fingerprint image background from its foreground is called image segmentation. Foreground contains clear ridges and valleys, whereas background has noisy ridges and valleys. To increase the performance of the automatic fingerprint system, background must be discarded from foreground image. We achieved the region of interest and discarded background using following two steps.

A. Block Direction Estimation

Foreground Region of Interest (ROI) of fingerprint image has dominant direction whereas background has no global direction. For block direction estimation, we have used algorithm proposed by Hong et al. in [7]. According to this algorithm:

- Divide input image into 16x16 blocks.
- Compute horizontal gradients g_x and vertical gradient g_y of each pixel in the block using two Sobel filters. Sobel operator is given in equation (3). Use transposed Sobel operator for g_y.

$$\begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} \tag{3}$$

- Compute direction θ for each block using formula

$$\theta = \frac{1}{2} tan^{-1} \left(\frac{2\sum\sum(g_x g_y)}{w^2 \sum\sum(g_x{}^2 - g_y{}^2)} \right) \tag{4}$$

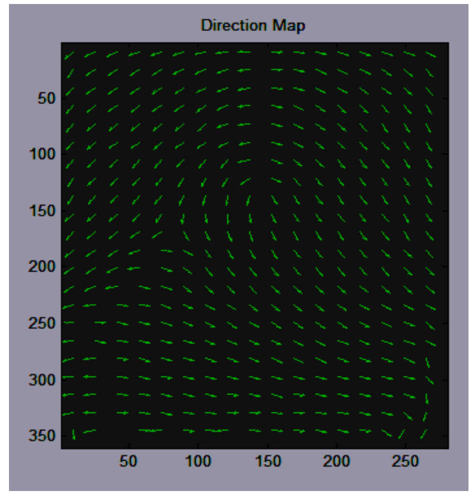

Fig. 8 Direction map, green arrows show direction of blocks

B. ROI Localization

After block direction estimation, we can find mask for ROI. This block is when multiplied by original image gives real ROI. To calculate the mask of ROI, first find the certainty level of each block by using following formula.

$$E = \frac{2\sum\sum(g_x g_y) + \sum\sum(g_x{}^2 - g_y{}^2)}{w^2 \sum\sum(g_x{}^2 + g_y{}^2)} \tag{5}$$

Where E is certainty level and W=16.

If the certainty level (E) is greater than or equal to threshold T, then it is considered as a ROI block [8]. Some morphological operations like 'OPEN' and 'CLOSE' are also used to remove peaks established by background noise.

VI. IMAGE THINNING AND MINUTIA MARKING

Thinning is morphological operation which erodes away ridges until they are one pixel wide. To thin a fingerprint image, standard thinning algorithm proposed by Guo et. al. in [8] was applied.

In this stage, minutiae are extracted from thinned fingerprint image and saved into template file. Crossing Number (CN) method is used for marking minutiae. According to this method:

- First label ridges in thinned image.
- Select a ridge and scanned neighbors of each pixel in ridge using a 3x3 matrix/window. Central element of window must be pixel value of the ridge under operation. Use masks given in Fig. 9 to identify ridge terminations and ridge bifurcations.

EE

0	0	1
0	1	0
0	0	0

i. Termination

1	0	1
0	1	0
0	1	0

(b) Bifurcation

Fig. 9 Ridge Ending and Bifurcation Masks

- If central pixel is 1 and have only one neighbor pixel with value 1, mark it as a ridge termination.
- If central pixel is 1 with exactly 3 neighbors with pixel value 1, mark it as a bifurcation.

To represent minutiae according to NIST in [4], we have used algorithm proposed and discussed by Mehtre et. al. and Kumar et. al. in [2, 15].

A bifurcation can be divided into three ridge terminations. Each of the three new terminations is considered as a separate minutia. Each minutia is characterized by three parameters; 1) Location of minutia 2) Orientation of minutia 3) Series of x-coordinate of associated ridge with specified length 'Lpath'. To find orientation (β) track a ridge segment of length 'Lpath' with starting point minutiae location. Add up all x-coordinates of points in the ridge and divide this summation with 'Lpath' to get δx (i.e. δx =∑xi/Lpath). Similarly find δy, then use formula:

$$tan\beta = \frac{(\delta y - y_o)}{(\delta x - x_o)} \qquad (6)$$

where (x_o, y_o) is minutia location.

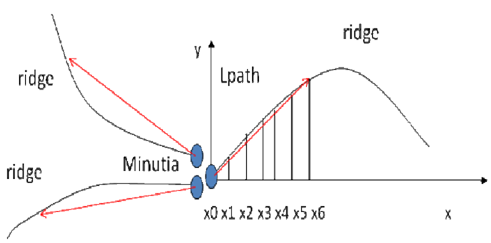

Fig. 10 Ridge bifurcation representation

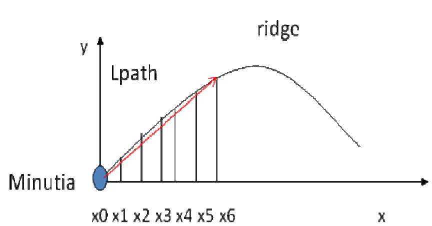

Fig. 11 Ridge termination representation

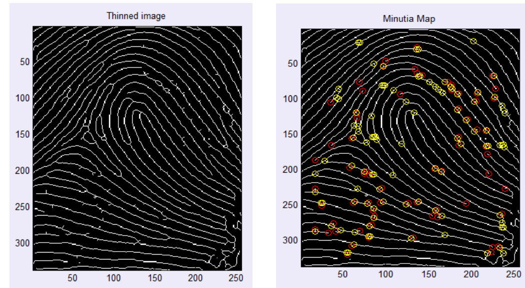

Fig. 12 Thinned Map and Minutia Map

VII. REMOVING FALSE MINUTIA

Enhancement techniques do not fix the fingerprint image completely. In reality, some false ridge breaks and false ridge cross-connections are not completely eliminated due to the quality of fingerprint sensors. Also all earlier stages produce some artifacts and lead to false minutiae in minutiae marking stage. These false minutiae were removed by algorithm proposed by Kumar in [15].

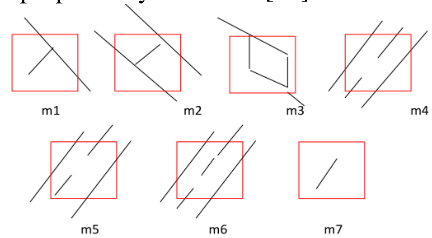

Fig. 13 Seven types of false minutia

According to this method:

- Calculate the average inter-ridge width (I). It can be calculated by the following steps:
  1. Scan a row of thin ridged image and add up all pixels whose value is 1.
  2. Divide row length by above summation to get the ridge width (I). Perform this operation on several other rows and columns to improve accuracy.
- Select a minutia pair and calculate the distance between selected minutia using distance formula:

$$D = \sqrt{(x_2 - x_1)^2 + (x_2 - x_1)^2} \qquad (7)$$

- If the distance D between one termination and one bifurcation is less than the average inter-ridge width I and both the minutiae are on a same ridge, discard both of them.
- If the distance D between two bifurcations is less than average inter-ridge width I and both the minutiae are on a same ridge, remove both of them.
- If the distance D between two terminations is less than average inter-ridge width and both of the minutiae are not on a same ridge, simply discard both of them, as both are broken points of a single ridge.

- If two terminations are on a same ridge and the length of the ridge is less than average inter-ridge width I, then discard both of the minutia's.

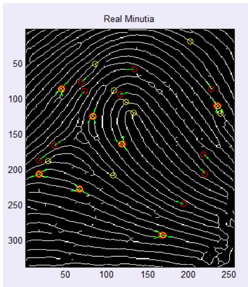

Fig. 14 Real Minutia

VIII. MINUTIA MATCHING

Minutia Matching is very important in making decision. If minutia matching algorithm is robust enough, it will correctly classify test image. In this regard, we have used algorithm proposed by Chang et al. (1997) for minutiae matching. Given two fingerprint templates, similarity can be checked by applying following steps:

- Select any two minutiae one from each image.
- Find the similarity (S) of two selected minutia using formula:

$$S = \frac{\sum_{i=0}^{n}(x_i X_i)}{\sqrt{\sum_{i=0}^{n}(x_i^2 X_i^2)}} \tag{8}$$

Where $x_1, x_2 \ldots\ldots x_n$. and $X_1, X_2, \ldots\ldots\ldots X_n$. are the x-coordinates of ridges associated with two minutiae.

If similarity between two reference minutiae is greater than the threshold value let say 80%, go to next step. Otherwise, continue matching among other minutiae pairs.

- Make one of two matched minutiae as a reference
- Translate and rotate all the minutiae with respect to reference minutia using affine transform matrix given below:

$$TM = \begin{bmatrix} cos\theta & -sin\theta & 0 \\ sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{10}$$

- Superimpose minutiae in two aligned images and place a bounding box around minutiae. If any two minutiae from different templates are inside the box and have small difference in their orientation. They are matched minutiae.
- If matching score is greater than threshold value let say 80%, then two fingerprints templates belong to same person.

IX. EXPERIMENTAL RESULTS

For this research a database of 325 fingerprint image was created. Verification was a carried out on all images while identification was made only for 310 images. Verification is described as when an unknown subject is compared against a specific subject in the database for his/her verification. Identification is defined when an unknown subject is compared against all the subjects in the database. The system specification for the execution of code was MATLAB 2013R, installed on Core i-III processor, with 2GB RAM on an HP Machine.

	Verification	Identification
Testing	325	310
Correct answers	298	302
Accuracy	91.6	97.4
Speed	45 sec	21 sec

Table 1

From the table, it is quite evident that the accuracy of system is comparable with the existing finger print matching techniques. The limitation of this matching algorithm is that is variant to image rotation, translation and scaling. This problem can be circumvented by employing Affine Transform. Moreover, the results can be improved further by using Scale Invariant Feature Transform (SIFT) or Speed Up Robust Feature (SURF).

X. CONCLUSION

In this paper, we have combined different techniques to develop an automatic fingerprint system. We have developed a MATLAB GUI to check the performance of a practical system. The key point that determines the performance and efficiency of an automatic fingerprint system is the precision in marking minutia during the process of minutia marking. The efficiency of this algorithm can be improved by including robust search algorithm and using high quality scanner.

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