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Fingerprint Verification System using Minutiae Extraction Technique

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Abstract**—**Most fingerprint recognition techniques are based on minutiae matching and have been well studied. However, this technology still suffers from problems associated with the handling of poor quality impressions. One problem besetting fingerprint matching is distortion. Distortion changes both geometric position and orientation, and leads to difficulties in establishing a match among multiple impressions acquired from the same finger tip. Marking all the minutiae accurately as well as rejecting false minutiae is another issue still under research. Our work has combined many methods to build a minutia extractor and a minutia matcher. The combination of multiple methods comes from a wide investigation into research papers. Also some novel changes like segmentation using Morphological operations, improved thinning, false minutiae removal methods, minutia marking with special considering the triple branch counting, minutia unification by decomposing a branch into three terminations, and matching in the unified x-y coordinate system after a two-step transformation are used in the work.

Keywords**—**Biometrics, Minutiae, Crossing number, False Accept Rate (FAR), False Reject Rate (FRR).

I. Introduction

BIOMETRICS; are automated methods of recognizing an individual based on their physiological (e.g., fingerprints, face, retina, iris) or behavioral characteristics (e.g., gait, signature). Each biometric has its strengths and weaknesses and the choice typically depends on the application. No single biometric is expected to effectively meet the requirements of all the applications. Fingerprint recognition has a very good balance of all the properties. A number of biometric characteristics are being used in various applications as Universality, Uniqueness, Permanence, Measurability, Performance, Acceptability, and Circumvention [1].

A. What is a Fingerprint?

A fingerprint is the feature pattern of one finger [10]. Each person has his own fingerprints with the permanent uniqueness. However, shown by intensive research on fingerprint recognition, fingerprints are not distinguished by their ridges and furrows, but by Minutia, which are some abnormal points on the ridges as shown in Fig. 1. Among the variety of minutia types reported in literature, two are mostly significant and in heavy usage: one is called termination, which is the immediate ending of a ridge; the other is called bifurcation, which is the point on the ridge from which two branches derive.

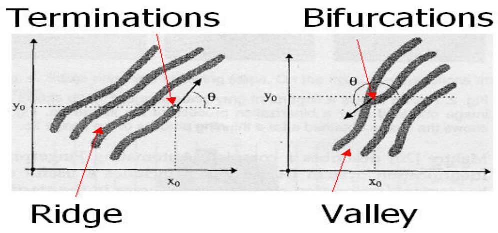

Fig. 1 Minutia (Valley is also referred as Furrow, Termination is also called Ending, and Bifurcation is also called Branch)

B. What is Fingerprint Recognition?

The fingerprint recognition problem can be grouped into three sub-domains: fingerprint enrollment, verification and fingerprint identification. 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. Verification is typically used for positive recognition, where the aim is to prevent multiple people from using the same identity. Fingerprint verification is to verify the authenticity of one person by his fingerprint. There is one-to-one comparison in this case. In the identification mode, the system recognizes an individual by searching the templates of all the users in the database for a match. Therefore, the system conducts a one-to-many comparison to establish an individual's identity.

C. Techniques for Fingerprint Recognition

Following are Fingerprint Recognition Techniques:

1. Minutiae Extraction Technique

Most of the finger-scan technologies are based on Minutiae. Minutia-based techniques represent the fingerprint by its local features, like terminations and bifurcations. This approach has been intensively studied, also is the backbone of the current available fingerprint recognition products [4]. This work also concentrates on same approach.

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2. *Pattern Matching or Ridge Feature Based Techniques*

Feature extraction and template generation are based on series of ridges as opposed to discrete points which forms the basis of Pattern Matching Techniques. The advantage of Pattern Matching techniques over Minutiae Extraction is that minutiae points may be affected by wear and tear and the disadvantages are that these are sensitive to proper placement of finger and need large storage for templates.

3. *Correlation Based Technique*

Let $I^{(\Delta x,\ \Delta y,\ \theta)}$ represent a rotation of the input image I by an angle θ around the origin (usually the image center) and shifted by Δx and Δy pixels in directions x and y, respectively. Then the similarity between the two fingerprint images T and I can be measured as

$$S(T,I) = \max_{\Delta x,\Delta y,\theta} CC(T, I^{(\Delta x,\Delta y,\theta)}) \qquad (1)$$

where CC(T, I) = $T^T I$ is the cross-correlation between T and I [2]. The cross-correlation is a well known measure of image similarity and the maximization in (1); it allows us to find the optimal registration. The direct application of (1) rarely leads to acceptable results, mainly due to the following problems:

a) Non-linear distortion makes impressions of the same finger significantly different in terms of global structure; the use of local or block-wise correlation techniques can help to deal with this problem.
b) Skin condition and finger pressure cause image brightness, contrast, and ridge thickness to vary significantly across different impressions. The use of more sophisticated correlation measures may compensate for these problems.
c) A direct application of (1) is computationally very expensive. Local correlation and correlation in the Fourier domain can improve efficiency.

4. *Image-based Techniques*

Image based techniques tries to do matching based on the global features of a whole fingerprint image. It is an advanced and newly emerging method for fingerprint recognition. It is useful to solve some intractable problems of the first approach.

II. Design and Implementation of Fingerprint Verification System using Minutiae Extraction Technique

A. *System Level Design*

A fingerprint recognition system constitutes of Fingerprint acquiring device for generating digital image of fingerprint, Minutia Extractor and Minutia Matcher as show in the Fig. 2.

Fig. 2 System level Design

B. *Algorithm Level Design*

To implement a minutia extractor, a three-stage approach is widely used by researchers. These stages are preprocessing, minutia extraction and post processing stage. The steps of the complete process used in the work are shown in Fig. 3.

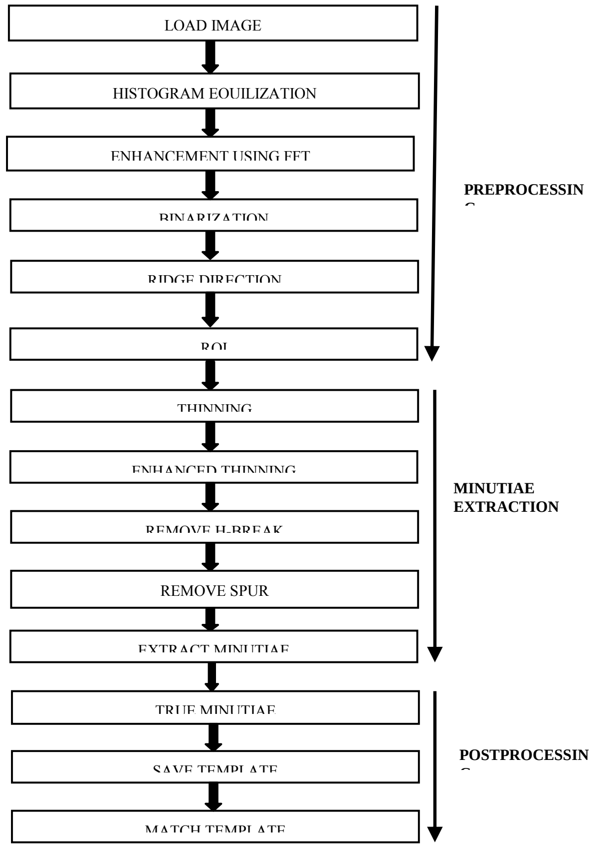

Fig. 3 Algorithm level Design

C. *Fingerprint Image Preprocessing*

Following are the various steps during image preprocessing stage

1. *Fingerprint Image Enhancement*

Fingerprint Image enhancement is to make the image clearer for easy further operations. Since the fingerprint images acquired from sensors or other media are not assured with perfect quality, enhancement methods, for increasing the contrast between ridges and furrows and for connecting the false broken points of ridges due to insufficient amount of ink, are very useful to keep a higher accuracy to fingerprint recognition. Two methods are adopted in the work: the first one is Histogram Equalization; the second one is Fourier Transform.

2. *Fingerprint Image Binarization*

A locally adaptive binarization method is performed to binarize the fingerprint image. Such a named method comes from the mechanism of transforming 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

3. Fingerprint Image Segmentation

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 minutia in the bounded region is confusing with those spurious minutias that are generated when the ridges are out of the sensor. To extract the ROI, a two-step method is used. The first step is block direction estimation and direction variety check, while the second is intrigued from some Morphological methods. Two Morphological operations called 'OPEN' and 'CLOSE' are adopted. The 'OPEN' operation can expand images and remove peaks introduced by background noise. The 'CLOSE' operation can shrink images and eliminate small cavities.

B. Minutia Extraction

Minutiae Extraction steps are explained below

1. Fingerprint Ridge Thinning

Thinning is the process of reducing the thickness of each line of patterns to just a single pixel width [5, 7]. The requirements of a good thinning algorithm with respect to a fingerprint are

a) The thinned fingerprint image obtained should be of single pixel width with no discontinuities.
b) Each ridge should be thinned to its centre pixel.
c) Noise and singular pixels should be eliminated.
d) No further removal of pixels should be possible after completion of thinning process.

[8] Uses 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). And finally removes all those marked pixels after several scans. But it is tested that such an iterative, parallel thinning algorithm has bad efficiency although it can get an ideal thinned ridge map after enough scans. [3] Uses a one-in-all method to extract thinned ridges from gray-level fingerprint images directly. Their method traces along the ridges having maximum gray intensity value. However, binarization is implicitly enforced since only pixels with maximum gray intensity value are remained. The advancement of each trace step still has large computation complexity although it does not require the movement of pixel by pixel as in other thinning algorithms. Thus the third method is bid out which uses the built-in Morphological thinning function in MATLAB to do the thinning and after that an enhanced thinning algorithm is applied to obtain an accurately thinned image.

2. Enhanced Thinning

Ridge Thinning is to eliminate the redundant pixels of ridges till the ridges are just one pixel wide. Ideally, the width of the skeleton should be strictly one pixel. However, this is not always true. There are still some locations, where the skeleton has a two-pixel width at some erroneous pixel locations. An erroneous pixel is defined as the one with more than two 4-connected neighbors. These erroneous pixels exist in the fork regions where bifurcations should be detected, but they have CN = 2 instead of CN>2. The existence of erroneous pixels may

a) destroy the integrity of spurious bridges and spurs,
b) exchange the type of minutiae points, and
c) miss detect true bifurcations,

Therefore, before minutiae extraction, there is a need to develop a validation algorithm to eliminate the erroneous pixels while preserving the skeleton connectivity at the fork regions. For this purpose an enhanced thinning algorithm is bid out.

Enhanced thinning algorithm

Step 1: Scanning the skeleton of fingerprint image row by row from top-left to bottom-right. Check if the pixel is 1.
Step 2: Count its four connected neighbors.
Step 3: If the sum is greater that two, mark it as an erroneous pixel.
Step 4: Remove the erroneous pixel.
Step 5: Repeat steps 1 – 4 until whole of the image is scanned and the erroneous pixels are removed.

3. Minutia Marking

After the fingerprint ridge thinning, marking minutia points is the next important step. As the number of minutiae detected is more the probability of accurate result increases. The concept of Crossing Number (CN) is widely used for extracting the minutiae. Rutovitz's definition of crossing number for a pixel P is given by (2)

$$C_n(P) = (\frac{1}{2})\sum_{i=1}^{8} | P_i - P_{i+1} | \quad (2)$$

where P_i is the binary pixel value in the neighborhood of P with P_i = (0 or 1) and $P_1 = P_9$. The crossing number Cn(P) at a point P is defined as half of cumulative successive differences between pairs of adjacent pixels belonging to the 8-neighborhood of P. In traditional methods the minutiae detection on the binary skeleton had been performed by labeling as minutiae those pixels whose crossing number was different from 2. Some methods consider the pixels having Cn(P) =1 corresponds to ridge ending, while the pixels which had Cn(P)>=3 correspond to bifurcation or if Cn(P) =2 it correspond to ridge ending, while the pixels which had Cn(P)=6 correspond to bifurcation. [9] Suggested that ridge ending can be found at crossing number Cn(P)>=1 to Cn(P) =2 and bifurcation at crossing number starting from Cn(P)>=1.

But it was found that the condition given below is the most effective one and it detects all the bifurcations and ends as the image till this step is perfectly thinned to one pixel width. If Cn(P) = = 1 it's a ridge end and if Cn(P) = = 3 it's a ridge bifurcation point. As more concentration is given on ridge endings and ridge bifurcations only so this is the best condition and there is no need to consider Cn(P) > 3 because it's a crossing point. After applying enhanced thinning algorithm the possible bifurcation templates are shown in Fig. 4.

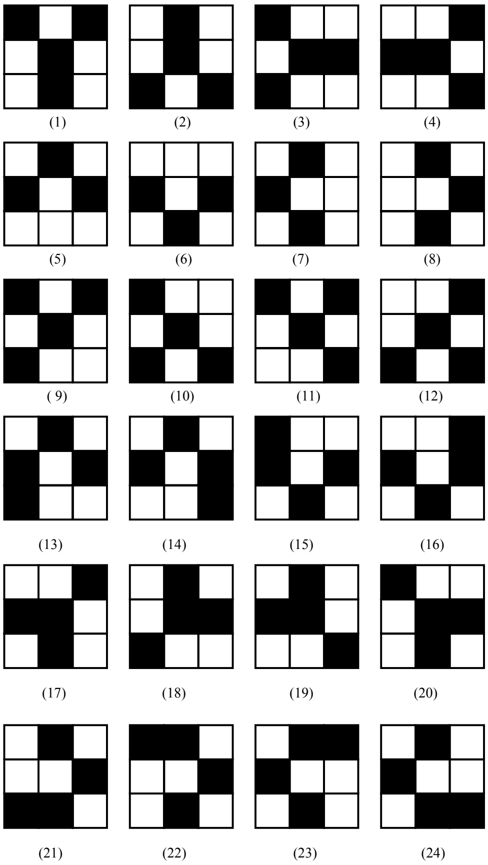

Fig. 4 Bifurcation Templates

C. Minutia Postprocessing

Minutiae Postprocessing steps are explained below:

1. False Minutia Removal

The preprocessing stage does not totally heal the fingerprint image. For example, false ridge breaks due to insufficient amount of ink and ridge cross-connections due to over inking are not totally eliminated [8]. Actually all the earlier stages themselves occasionally introduce some artifacts which later lead to spurious minutia. Twelve types of false minutia are specified in Fig. 5:

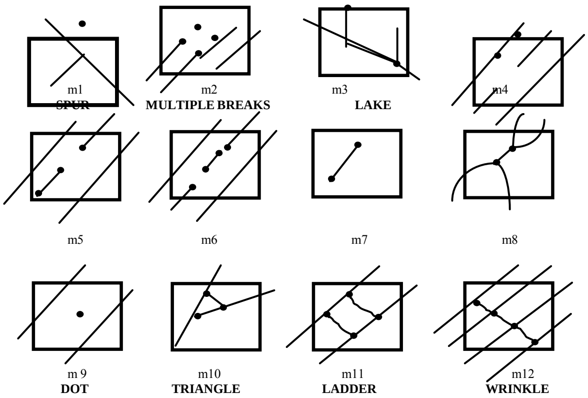

Fig. 5 False Minutia Structures

Procedures to remove false minutia are:

a) If the distance between one bifurcation and one termination is less than D and the two minutias are in the same ridge (m1 case). Remove both of them. D is the average inter-ridge width representing the average distance between two parallel neighboring ridges.
b) If the distance between two bifurcations is less than D and they are in the same ridge, remove the two bifurcations (m2, m3, m8, m10, m11 cases).
c) 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).
d) If two terminations are located in a short ridge with length less than D, remove the two terminations (m7).
e) If a branch point has at least two neighboring branch points, which are each no further away than maximum distance threshold value and these branch points are closely connected on common line segment than remove the branch points (m12).

2. Minutia Match

Given two set of minutia of two fingerprint images, the minutia match algorithm determines whether the two minutia sets are from the same finger or not. An alignment-based match algorithm partially derived from the [6] is used in this work. It includes two consecutive stages: one is alignment stage and the second is match stage.

a) Alignment stage: Given two fingerprint images to be matched, choose any one minutia from each image; calculate the similarity of the two ridges associated with the two referenced minutia points. If the similarity is larger than a threshold, transform each set of minutia to a new coordination system whose origin is at the referenced point and whose x-axis is coincident with the direction of the referenced point.
b) Match stage: After the set of transformed minutia points is derived, the elastic match algorithm is used to count the

matched minutia pairs by assuming two minutia having nearly the same position and direction are identical.

III. Results

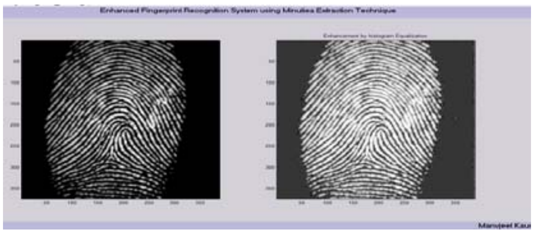

Fig. 6 Histogram Enhancement. Original Image (Left). Enhanced image (Right)

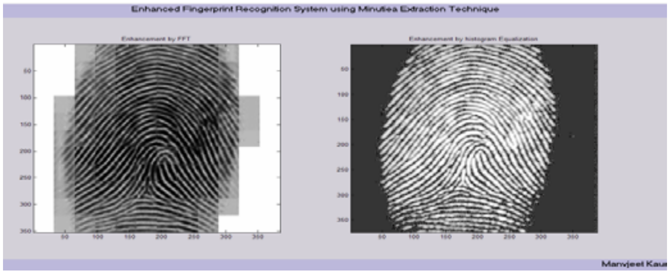

Fig. 7 Fingerprint enhancement by FFT Enhanced image (left), Original image (right)

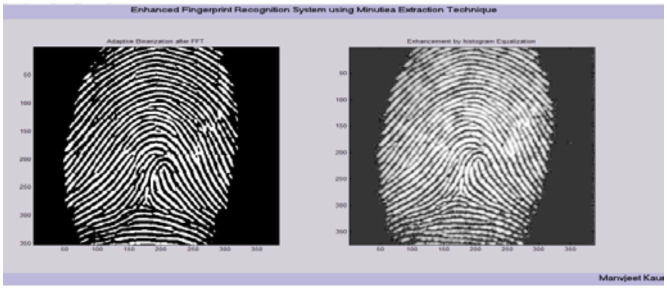

Fig. 8 the Fingerprint image after adaptive binarization Binarized image (left), Enhanced gray image (right)

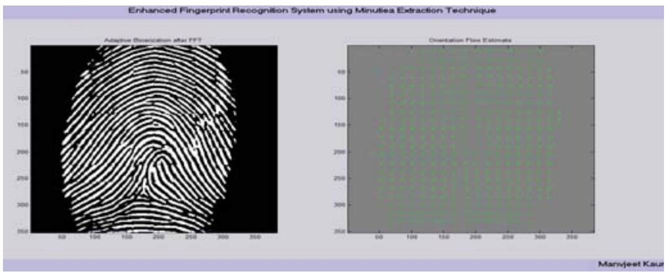

Fig. 9 Direction map. Binarized fingerprint (left), Direction map (right)

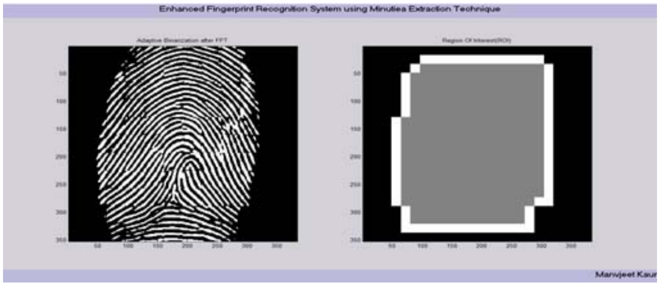

Fig. 10 ROI + Bound

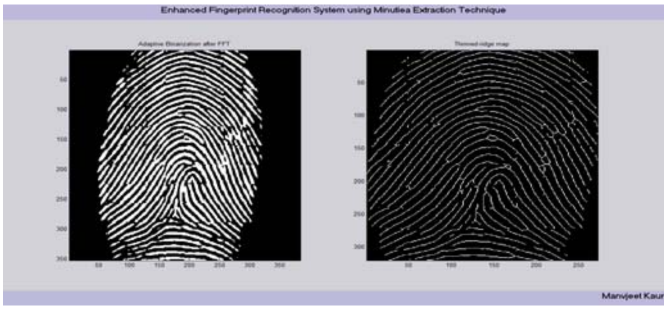

Fig. 11 Thinned Image

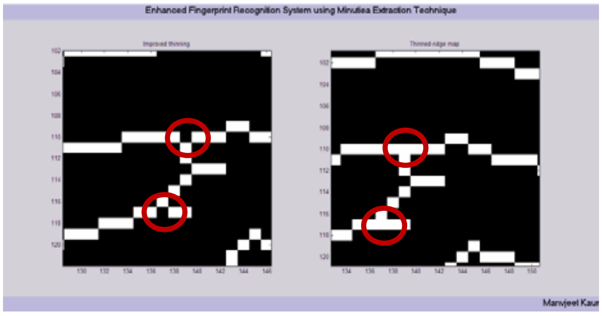

Fig. 12 Results of improved thinning algorithm

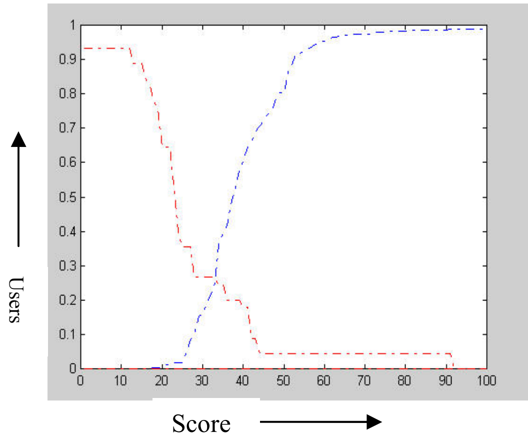

Fig. 13 FAR and FRR curve Blue dot line: FRR curve Red dot line: FAR curve

The above Fig. 13 shows the FRR and FAR curves. At the equal error rate 25%, the separating score 33 will falsely reject 25% genuine minutia pairs and falsely accept 25% imposturous minutia pairs and has 75% verification rate.

The high incorrect acceptance and false rejection are due to some fingerprint images with bad quality. Furthermore, good experiment designs can surely improve the accuracy. Further studies on good designs of training and testing are expected to improve the result.

IV. Conclusion and Future Scope

Improved thinning in the present work contributes to:

a) The image becomes perfectly thinned to single pixel width.

b) More number of bifurcations can be detected, which were missed earlier due to the presence of erroneous pixels in the thinned image.

False Minutiae Removal techniques contribute to:

a) Twelve different false minutiae are detected and are removed properly.

b) Probability of getting refined image free of erroneous minutiae will be more.

All the possible end and bifurcation templates are generated. There can be 24 bifurcation templates as identified in this work. During Match stage the bifurcation is considered as a combination of three terminations. It improves the coding as it saves the execution time for testing bifurcations separately. Also a program coding with MATLAB going through all the stages of the fingerprint recognition is built. It is helpful to understand the procedures of fingerprint recognition. And demonstrate the key issues of fingerprint recognition.

Overall, a set of reliable techniques have implemented for fingerprint image enhancement and minutiae extraction. These techniques can then be used to facilitate the further study of the statistics of fingerprints.

The future scope of the work is to improve the quality of image either by improving the hardware to capture the image or by improving the image enhancement techniques, So that the input image to the thinning stage could be made better which can improve the future stages and the final outcome.

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