Optimization Technique for Fingerprint Recognition and Matching

Dr. S. Latha Shanmugavadivu [1], Dr. M. Rajaram [2]

[1.] Department of ECE, Tamilnadu College of Engineering, Coimbatore - 641656.
[2.] Department of Electrical Engineering, Government College of Technology, Coimbatore - 641013.
latha_tce@yahoo.co.in

Abstract: This work investigates the current techniques for fingerprint recognition. This target can be mainly decomposed into image preprocessing, feature extraction and feature match. For each sub-task, some classical and up-to-date methods in literatures are analyzed. Based on the analysis, an integrated solution for fingerprint recognition is developed for demonstration. A novel fingerprint reconstruction algorithm is proposed to reconstruct the phase image, which is then converted into the grayscale image. The proposed reconstruction algorithm not only gives the whole fingerprint, but the reconstructed fingerprint contains very few spurious minutiae. Specifically, a fingerprint image is represented as a phase image which consists of the continuous phase and the spiral phase which corresponds to minutiae. An algorithm is proposed to reconstruct the continuous phase from minutiae. The optimization at coding level and algorithm level are proposed to improve the performance of the fingerprint recognition system.

[Latha Shanmugavadivu S, Rajaram M. **Optimization Technique for Fingerprint Recognition and Matching**. *Life Sci J* 2013;10(9s):289-296] (ISSN:1097-8135). http://www.lifesciencesite.com. 41

Keywords: Finger print recognition; continuous phase; minutiae; phase image; grayscale image

1. Introduction

Fingerprints have been used for over a century and are the most widely used form of biometric identification. Fingerprint identification is commonly employed in forensic science to support criminal investigations, and in biometric systems such as civilian and commercial identification devices. Despite this widespread use of fingerprints, there has been little statistical work done on the uniqueness of fingerprint minutiae. In particular, the issue of how many minutiae points should be used for matching a fingerprint is unresolved.

The fingerprint of an individual is unique and remains unchanged over a lifetime. A fingerprint is formed from an impression of the pattern of ridges on a finger. A ridge is defined as a single curved segment, and a valley is the region between two adjacent ridges. The minutiae, which are the local discontinuities in the ridge flow pattern, provide the features that are used for identification. Details such as the type, orientation and location of minutiae are taken into account when performing minutiae extraction. Galton defined a set of features for fingerprint identification, which since then, has been refined to include additional types of fingerprint features. However, most of these features are not commonly used in fingerprint identification systems. Instead the set of minutiae types are restricted into only two types, ridge endings and bifurcations, as other types of minutiae can be expressed in terms of these two feature types. Ridge endings are the points where the ridge curve terminates, and bifurcations are where a ridge splits from a single path to two paths at a Y-junction. Figure 1 illustrates an example of a ridge ending and a bifurcation. In this example, the black pixels correspond to the ridges and the white pixels correspond to the valleys.

Fingerprint images are rarely of perfect quality. They may be degraded and corrupted with elements of noise due to many factors including variations in skin and impression conditions.

Fingerprint recognition systems play a crucial role in many situations where a person needs to be verified or identified with high confidence. As a result of the interaction of genetic factors and embryonic conditions, the friction ridge pattern on fingertips is unique to each finger. Fingerprint features are generally categorized into three levels.

- Level 1 features mainly refer to ridge orientation field and features derived from it, i.e., singular points and pattern type.
- Level 2 features refer to ridge skeleton and features derived from it, i.e., ridge bifurcations and endings.
- Level 3 features include ridge contours, position, and shape of sweat pores and incipient ridges.

2. Literature Review

One of the most widely cited fingerprint enhancement techniques is the method employed by Hong et al. which is based on the convolution of the image with Gabor filters tuned to the local ridge orientation and ridge frequency. The main stages of this algorithm include normalization, ridge orientation estimation, ridge frequency estimation and filtering.

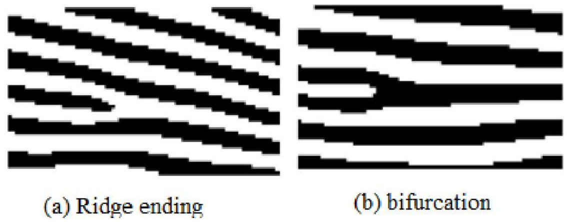

Fig 1: Example of a ridge ending and bifurcation

2.1 Existing system

Cappelli et al. (2007) proposed a technique to directly reconstruct the gray scale image from minutiae. The orientation field is estimated by fitting a modified model called Gabor Filtering is iteratively performed starting from minutiae on an image initialized by the local minutiae pattern. A rendering step is performed to make the reconstructed fingerprint image appear more realistic. The efficiency of this reconstruction algorithm was assessed by attacking nine fingerprint matching algorithms. An average True Accept Rate (TAR) of 75.43 percent at 0 percent False Accept Rate (FAR) was obtained in matching 120 reconstructed fingerprints against the 120 original fingerprints in FVC2002 DB1.However, this algorithm also generates many spurious minutiae in the reconstructed fingerprints.

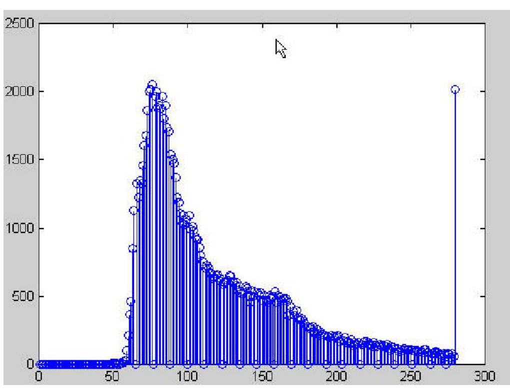

Figure 2: The Original histogram of a fingerprint image

Maltoni et al (2009) used the well-known SFINGE fingerprint synthesis method which performs Gabor filtering on a seed image according to the orientation and frequency images; minutiae automatically emerge during the filtering procedure. Some intra class variations, such as spatial transformation, touching area, nonlinear distortion, ridge dilation/shrinking and noise are simulated to generate realistic impressions of the master fingerprint. One main limitation of SFINGE is that minutiae cannot be controlled. As a result, SFINGE may generate problematic fingerprints that contain too few minutiae or very long ridges.

Larkin and Fletcher (2007) proposed to represent a fingerprint image as a 2D amplitude and frequency modulated (AM-FM) signal which is composed of four components: the intensity offset the amplitude, the phase and the noise. Here, we are only interested in the phase since ridges and minutiae are totally determined by the phase. The other three components just make the fingerprint appear realistic. Therefore, an ideal fingerprint can be represented as a 2D FM signal: $I(x ,y)= \cos(\Psi(x ,y))$. In a fingerprint image, the direction of instantaneous frequency is normal to the local ridge orientation and the magnitude of instantaneous frequency is equal to the local ridge frequency.

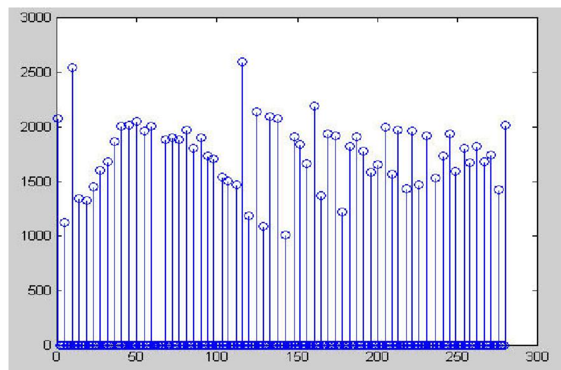

Figure 3: Histogram after the Histogram Equalization

D. Maio (2009) proposed to represent direct gray-scale minutiae detection in fingerprints. In this paper he has used a binary image-based technique, where he assume that the fingerprint image has been either acquired directly in binary or binarized from a gray-scale image. He assumes also that the image has been skeletonized. The problem in this methodology comes from the fact that a minutia in the skeleton image does not always correspond to a meaningful point in the real image. In fact, there are more than a thousand apparent ending or bifurcation points, while the real minutiae are less than 100. Such a behavior arises as a consequence of under inking, over-inking, wrinkle, scars and excessively worn prints and therefore, spurious minutiae can appear in the skeleton image after pre-processing.

The AFIS proposed by Stosz and Alyea (2008) uses pore positions coupled to other minutiae extracted from live scanned images: the quality of the valley skeleton is first improved by analyzing and extracting segments that represent pores (*cleaning*), then syntactic processing is used to remove undesirable artifacts: two disconnected ridges are connected if their distance is less than a given threshold and endpoint directions are almost the same wrinkles are detected by analyzing information on neighboring branch points.

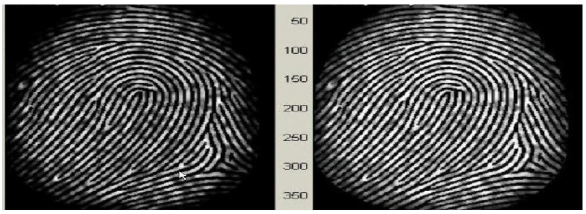

Figure 4: Histogram Enhancement; Original Image (Left). (b) Enhanced image (Right)

Xiao and Raafat (2008) assume that fingerprints have already been pre-processed and skeletonized. They propose a post-processing based on a combined statistical and structural approach. Fingerprint minutiae are characterized by a set of attributes like the ridge length, the direction for endpoints and bifurcations, the angle between two minutiae. Moreover, each endpoint or bifurcation is also characterized by the number of "facing" minutiae in its neighborhood. The neighborhood area depends on the local distance between ridges. Finally, the number of "connected" minutiae is evaluated.

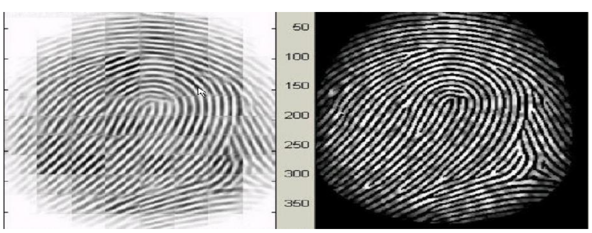

Figure 5: Fingerprint enhancement by FFT; Ehanced image (left), Original image (right)

Hill (2007) proposed a technique to determine the fingerprint structure from minutiae template (including singular points). In this work, orientation field was generated based on singular points. A line drawing algorithm was used to generate a sequence of spurious lines passing through the minutiae.

Ross et al (2007) first estimated the orientation field using selected minutiae triplets in the template. Stream lines were then traced starting from minutiae and border points. Linear Integral Convolution was used to impart texture-like appearance to the ridges. Finally, the image was smoothed to obtain wider ridges. This reconstruction algorithm can only generate a partial fingerprint.

Jianjiang Feng and Anil K. Jain (2009) proposed representing FM Model Based Fingerprint Reconstruction from Minutiae Template. In this paper, a novel fingerprint reconstruction algorithm is proposed, which not only reconstructs the whole fingerprint, but the reconstructed fingerprint contains very few spurious minutiae.

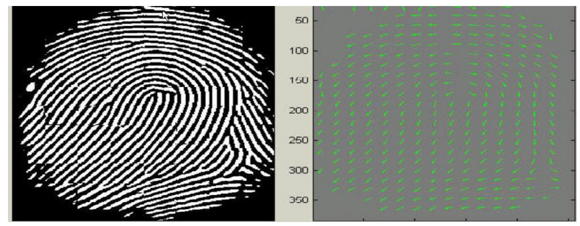

Figure 6: Direction map; Binarized fingerprint (left), Direction map (right)

2.2 Drawbacks

- Fingerprint recognition is vulnerable to noise and distortion brought on by dirt and twists. Some people may feel offended about placing their fingers on the same place where many other people have continuously touched. Some people have damaged or eliminated fingerprints.
- Overall, it can be seen that most techniques for fingerprint image enhancement are based on filters that are tuned according to the local characteristics of fingerprint images.
- Ridges of the fingerprint are just lines that when leave the frame of view go off to infinity.
- If two fingerprints can be shown to be nearly topologically equivalent then they are most likely the same fingerprint.

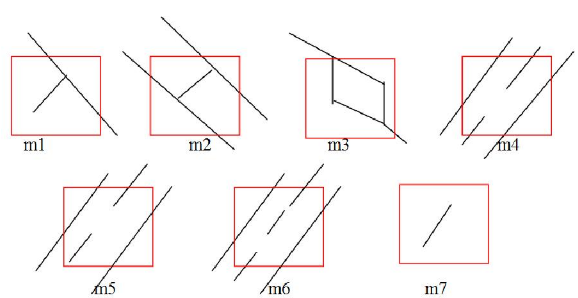

Figure 7: False Minutia Structures

2.3 Proposed system

This research is to investigate the current techniques for fingerprint recognition. This target can be mainly decomposed into image preprocessing, feature extraction and feature matching. Based on the analysis, an integrated solution for fingerprint recognition is developed for demonstration. The phase is composed of the continuous phase and the spiral phase. A reconstructed fingerprint is obtained by reconstructing the orientation field, reconstructing the continuous phase and combining the continuous phase with the spiral phase.

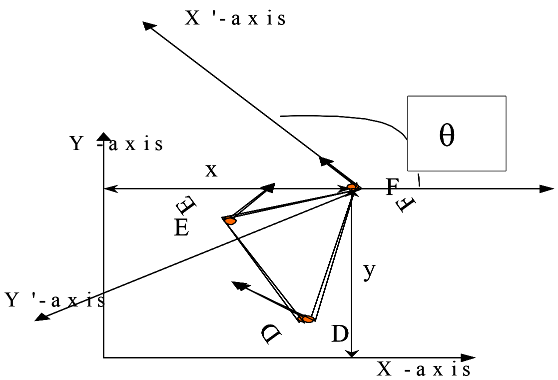

Figure 8: Translation and Rotation

The reconstruction method to the difficult and important problem of latent fingerprint restoration is done here. The ridge flow and minutiae in the reconstructed fingerprint match the original fingerprint well. Demonstration program is coded by MATLAB. For the program optimization at coding level and algorithm level are proposed to improve the performance of fingerprint recognition system. These performance enhancements are shown by experiments conducted upon a variety of fingerprint images.

2.4 Software requirements

This research work is done using MATLAB.The main advantage of choosing this software is that it is user friendly, simple codes, easy to design, platform independent, predefined functions, easy to plot.

3. Implementation

The fingerprint image preprocessing stage consists of six important processes they are as follows.

3.1 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, those 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.

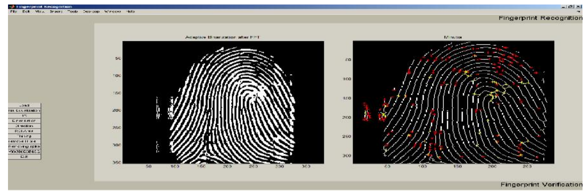

Figure 9: Minutia Extraction

The quality of the ridge structures in a fingerprint image is an important characteristic, as the ridges carry the information of characteristic features required for minutiae extraction. Ideally, in a well-defined fingerprint image, the ridges and valleys should alternate and flow in locally constant direction. This regularity facilitates the detection of ridges and consequently, allows minutiae to be precisely extracted from the thinned ridges. However, in practice, a fingerprint image may not always be well defined due to elements of noise that corrupt the clarity of the ridge structures. This corruption may occur due to variations in skin and impression conditions such as scars, humidity, dirt and non-uniform contact with the fingerprint capture device. Thus, image enhancement techniques are often employed to reduce the noise and enhance the definition of ridges against valleys.

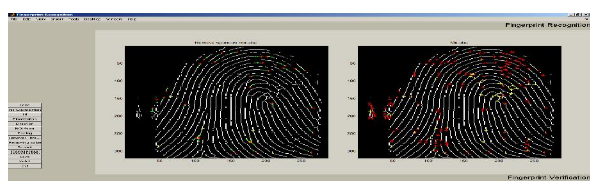

Figure 10: Real minutiae

Two Methods are adopted in our fingerprint recognition system:

- Histogram Equalization.
- Fourier Transform.

3.2 Histogram equalization

The histogram of an image is a function that provides the frequency of occurrence for each intensity level in the image as a graphical representation. Histogram is made up of bins, each bin representing a certain intensity value range. Each pixel is assigned to a bin depending on the pixel intensity; the final value of a bin is the number of pixels assigned to it.

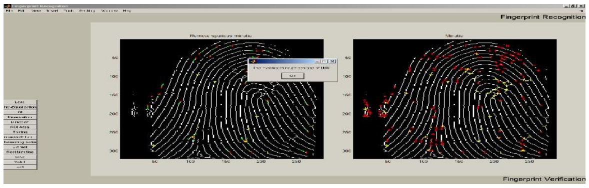

Figure 11: Fingerprint match

Histogram equalization is to expand the pixel value distribution of an image so as to increase the perceptional information. The original histogram of a fingerprint image has the bimodal type Figure 1.2, the histogram after the histogram equalization occupies all the range from 0 to 255 and the visualization effect is enhanced Figure 3.

3.3 Fingerprint Enhancement by Fourier Transform

The image is divided into small processing blocks (32 by 32 pixels) and the Fourier transform is performed according to:

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

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)|.

Get the enhanced block according to

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

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

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

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

The k in formula (2) is an experimentally determined constant, which we choose k=0.45 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. Figure 4.4 presents the image after FFT enhancement.

The enhanced image after FFT has the improvements to connect some falsely broken points on ridges and to remove some spurious connections between ridges. The shown image at the left side of figure 5 is also processed with histogram equalization after the FFT transform.

3.4 Binarization

Most minutiae extraction algorithms operate on binary images where there are only two levels of interest: the black pixels that represent ridges, and the white pixels that represent valleys. Binarization is the process that converts a gray-level image into a binary image. This improves the contrast between the ridges and valleys in a fingerprint image and consequently facilitates the extraction of minutiae.

The binarization process involves examining the gray-level value of each pixel in the enhanced image and if the value is greater than the global threshold, then the pixel value is set to a binary value one otherwise, it is set to zero. The outcome is a binary image containing two levels of information, the foreground ridges and the background valleys.

3.5 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 bound 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 block direction estimation and direction variety check.
- The intriguition from some Morphological methods.

3.6 Block direction estimation

- Estimate the block direction for each block of the fingerprint image with WxW in size (W is 16 pixels by default).
- 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.

$$tg2ß = 2 \quad (g_x*g_y)/ \quad (g_x^2-g_y^2) \qquad \text{---(4)}$$

The 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.

tg2 = 2sin cos /(cos^2 -sin^2) ---(5)

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

E = {2 $(g_x*g_y)+(g_x^2-g_y^2)\}/ W*W* (g_x^2+g_y^2)$ -(6)

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 figure 4.6. We assume there is only one fingerprint in each image.

3.7 Minutia extraction

Minutia extraction comes after the preprocessing of the finger print image. It involves two processes; they are ridge thinning and minutia marking.

3.8 Ridge Thinning

Ridge Thinning is to eliminate the redundant pixels of ridges till the ridges are just one pixel wide. It 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. In such an iterative, parallel thinning algorithm has bad efficiency although it can get an ideal thinned ridge map after enough scans. This method traces along the ridges having maximum gray intensity value. Also in our testing, 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.

3.9 Minutia post processing

In minutia post processing the removal of false minutia is done which is followed by the process of unifying bifurcations and terminations.

3.10 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. Actually all the earlier stages themselves occasionally introduce some artifacts which later lead to spurious minutia. These false minutias will significantly affect the accuracy of matching if they are simply regarded as genuine minutia.

Seven types of false minutia are specified in following diagrams:

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 only handles the case m1, m4, m5 and m6 and have not false minutia removal by simply assuming the image quality is fairly good.

The procedures for removing false minutia are:

- 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. Where D is the average inter-ridge width representing the average distance between two parallel neighboring ridges.
- If the distance between two bifurcations is less than D and they are in the same ridge, remove the two bifurcations (m2, m3 cases).
- 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).
- If two terminations are located in a short ridge with length less than D, remove the two terminations (m7).

3.11 Minutia matching

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 which is used in my project. It includes two consecutive stages: one is alignment stage and the second is match stage.

- 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.

- Match stage: After we get two set of transformed minutia points, we use the elastic match algorithm to count the matched minutia pairs by assuming two minutia having nearly the same position and direction are identical.

3.12 Alignment Stage

1. 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:
$S = {}^{m}{}_{i=0}x_iX_i/[{}^{m}{}_{i=0}x_i^2X_i^2]$^0.5, ---(7)
where ($x_{i\sim}x_n$) and ($X_{i\sim}X_N$) are the set of minutia for each fingerprint image respectively. 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. For each fingerprint, translate and rotate all other minutia with respect to the reference minutia according to the following formula:

$$\begin{pmatrix} xi\_new \\ yi\_new \\ \theta i\_new \end{pmatrix} = TM * \begin{bmatrix} (xi - x) \\ (yi - y) \\ (\theta i - \theta) \end{bmatrix},$$

where (x,y,) is the parameters of the reference minutia, and TM is

$$TM = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

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

This method uses the rotation angle calculated earlier by densely tracing a short ridge start from the minutia with length D. Since the minutia direction has been got already at the minutia extraction stage, obviously our method reduces the redundant calculation but still holds the accuracy. Here the approach is to transform each according to its own reference minutia and then do match in a unified x-y coordinate. Therefore, less computation workload is achieved through our method.

The matching algorithm for the aligned minutia patterns needs to be elastic since the strict match requiring that all parameters (x, y,) are the same for two identical minutia is impossible due to the slight deformations and inexact quantization's of minutia.

In this research minutia is matched by placing a bounding box around each template minutia. If the minutia to be matched is within the rectangle box and the direction discrepancy between them is very small, then the two minutias are regarded as a matched minutia pair. Each minutia in the template image either has no matched minutia or has only one corresponding minutia.

The final match ratio for two fingerprints is the number of total matched pair over the number of minutia of the template fingerprint. The score ranges from 0 to 100. If the score is larger than a pre-specified threshold, the two fingerprints are from the same finger.

4. Experimental Results

The reconstructed fingerprints still contain a few spurious minutiae, especially in the high curvature regions. The spurious minutiae can be avoided by (i) detecting and subtracting spirals from the continuous phase, or (ii) permitting the ridge frequency to vary in a reasonable range. To obtain reconstructed images more consistent with the original fingerprints, ridge frequency and minutiae type should be utilized. To make the reconstructed fingerprints more realistic, brightness, ridge thickness, pores and noise should be modeled. The experimental results show that the reconstructed image is very consistent with the original fingerprint.

The figure 9 shows the minutiae markings. It locates all minutiae and show them after the removal of spurious minutia. It save template file, including the minutia position, direction, and ridge information. It invokes the template file loader and does matching.

The figure 10 shows the result of real minutiae. This result can be obtained by removing the false minutiae after the minutiae extraction.

The figure 11 shows the result of fingerprint match. Minutiae are usually matched together by their distance relative to other minutiae around it. If multiple points in one image have similar distances between them then multiple points in another image then the points are said to match up.

5. Conclusion

A novel fingerprint reconstruction scheme has been proposed which is based on converting the minutiae representation to the phase representation. The phase is composed of the continuous phase and the spiral phase. A reconstructed fingerprint is obtained by reconstructing the orientation field, reconstructing the continuous phase and combining the continuous phase with the spiral phase. The experimental results show that the reconstructed image is very consistent with the original fingerprint and that there is a high chance of deceiving a state-of-the-art commercial fingerprint recognition system. Then the reconstructed image is then matched with the desired fingerprints. While the proposed algorithm is designed for fingerprint reconstruction, its underlying ideas, namely, representing fingerprints using phase, decomposing phase into continuous phase and spiral phase and modeling the continuous phase with piecewise polynomials, is also used in fingerprint enhancement and matching.

Corresponding Author:
Dr. S. Latha Shanmugavadivu,
Department of Electronics & Communication Engineering, Tamilnadu College of Engineering,
Coimbatore - 641656.
E-mail: latha_tce@yahoo.co.in

References

1. R. Cappelli A, Lumini D, Maio and D Maltoni. "Fingerprint Image Reconstruction from Standard Templates". IEEE Trans.Pattern Analysis and Machine Intelligence. 2007; 29(9): 1489- 1503.
2. J. Feng and A.K. Jain. "FM Model Based Fingerprint Reconstruction from Minutiae Template" Proc. Second Int'l Conf. Biometrics. 2009: 544-553.
3. FVC the Third Int'l Fingerprint Verification Competition; 2004: http://bias.csr.unibo.it/fvc2004.
4. K.G. Larkin and P.A. Fletcher. "A Coherent Framework for Fingerprint Analysis: Are Fingerprints Holograms?". Optics Express. 2007;15: 8667-8677.
5. D. Maltoni, A.K. Jain, and S. Prabhakar. Handbook of Fingerprint Recognition. second ed. Springer-Verlag; 2009.
6. D. Maio. Direct gray-scale minutiae detection in fingerprints, IEEE Trans; 2008.
7. NIST Special Database. NIST 8-Bit Gray Scale Images of Fingerprint Image Groups (FIGS). (4); 2010: http://www.nist.gov/srd/ nistsd4.htm.
8. K. Nandakumar, A.K. Jain, and S. Pankanti. "Fingerprint-Based Fuzzy Vault: Implementation and Performance," IEEE Trans. Information Forensics and Security. 2007; 2(4): 744-757.
9. NIST Minutiae Interoperability Exchange Test (MINEX); 2009: PAMI 19-27.
10. Ross A, Hill Jt, A K From template to image: Reconstructing fingerprints from minutiae points. IEEE Trans. 2007: 544-560.
11. J.D. Stosz L A Alyea. Automated system for fingerprint authentication using Pores & ridge structure. 2008; Proc.SPIE2277.

8/11/2013