



Fingerprint Recognition and Identification by Minutiae Detection and Phase Spectrum Analysis Algorithm

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Abstract: In this paper fingerprints are identified with the help of minutiae detection and phase spectrum analysis. This algorithm represents the fingerprint by calculating Minutiae & its local features, like terminations, bifurcations and Phase spectrum of all minutiae. The phase spectrum is calculated to characterize the minutiae structure in the neighborhood of a given minutia point. This is very good technique for fingerprint matching as algorithm gives excellent results. The matcher performs fairly accurate fingerprint matching for minutiae-based verification systems.

Keywords: Phase Spectrum, minutiae, bifurcations. Ridges

I. Introduction

A. What is a Fingerprint

Fingerprints are the patterns formed on the epidermis of the fingertip. The fingerprints are of three types: arch, loop and whorl. The fingerprint is composed of ridges and valleys. The interleaved pattern of ridges and valleys are the most evident structural characteristic of a fingerprint. There are three main fingerprint features:

- Global Ridge Pattern
- Local Ridge Detail
- Intra Ridge Detail



Fig. 1 Fingerprint Image

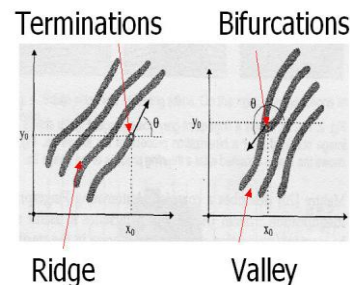


Fig. 2 Ridge and valley pattern in fingerprints

B. Approach for Fingerprint Recognition

There are two approaches for fingerprint recognition. They are image based approach, texture based approach and minutiae based approach. In image based matching, the image itself is used as the template. It requires only low resolution images. Matching is done by optical correlation and is extremely fast. It is based on the global features of a whole fingerprint image. However it requires accurate alignment of the fingerprint samples and is not favorable for changes in scale, orientation and position.

The second is the texture based approach. It uses texture information for matching and performs well with poor quality prints. However like image based matching it requires accurate alignment of the two prints and not invariant to translation, orientation and non-linear distortion.

Minutiae-based approach is the last approach. Here the ridge features called minutiae are extracted and stored in a template for matching. It is invariant to translation, rotation and scale changes. It is however error prone in low quality images. The minutiae based approach is applied. Usually before minutiae extraction, image preprocessing is performed.

C. Introduction about MDPSA

The MDPSA stands for “**Minutiae Detection & Phase Spectrum Analysis Algorithm**” is the current technique 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 and on the bases on the analysis, an integrated solution for fingerprint recognition is developed for demonstration.

Steps in MDPSA Algorithm:

Step1: Capture the image and perform Image Enhancement.

Step 2: Perform Image Equalization

Step 3: Apply Fast Fourier Transformation on above image

Step 4: Perform Image Binarization

Step 5: Perform image thinning to remove noise from, fingerprint Image.

Step 6: Mark all the Minutiae

Step 7: Remove False Minutiae

Step 8: Calculate Phase Spectrum of actual Minutiae

Step 9: Data matrix is generated to get the position, orientation and type of minutiae.

Step 10: Matching of test fingerprint with template.

Step 11: Matching score of two images is computed, if matching score is greater than 60% figure prints are matched otherwise not matched .

Step 12: Stop

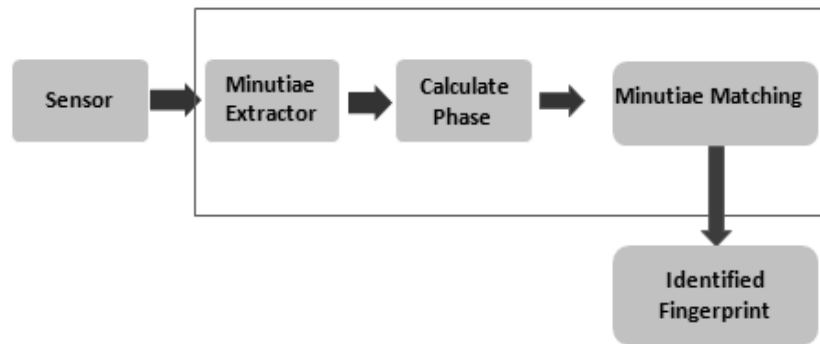


Fig. 3 Stages of MDPSA algorithm

i) Image Acquisition: Image acquisition is the first step in the approach. It is very important as the quality of the fingerprint image must be good and free from any noise. A good fingerprint image is desirable for better performance of the fingerprint algorithms. Based on the mode of acquisition, a fingerprint image may be classified as off-line or live-scan. An off-line image is typically obtained by smearing ink on the fingertip and creating an inked impression of the fingertip on paper. A live-scan image, on the other hand, is acquired by sensing the tip of the finger directly, using a sensor that is capable of digitizing the fingerprint on contact. Live-scan is done using sensors. There are three basic types of sensors used. They are optical sensors, ultrasonic sensors and capacitance sensors.

ii) Histogram Equalization: Histogram equalization is to expand the pixel value distribution of an image so as to increase the perceptual information. This method usually increases the global contrast of many images, especially when the usable data of the image is represented by close contrast values. Through this adjustment, the intensities can be better distributed on the histogram. This allows for areas of lower local contrast to gain a higher contrast. Histogram equalization accomplishes this by effectively spreading out the most frequent intensity values. The method is useful in images with backgrounds and foregrounds that are both bright or both dark. In particular, the method can lead to better views of bone structure in x-ray images, and to better detail in photographs that are over or under-exposed. A key advantage of the method is that it is a fairly straightforward technique and an invertible operator. So in theory, if the histogram equalization function is known, then the original histogram can be recovered. The calculation is not computationally intensive. A disadvantage of the method is that it is indiscriminate. It may increase the contrast of background noise, while decreasing the usable signal.

iii) Fingerprint Enhancement by Fourier Transform: The image is divided into small processing blocks (32 by 32 pixels) and perform the Fourier transform according to:

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

for $u = 0, 1, 2, \dots, 31$ and $v = 0, 1, 2, \dots, 31$.

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 = $\text{abs}(F(u, v)) = |F(u, v)|$.

Get the enhanced block according to

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

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

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

for $x = 0, 1, 2, \dots, 31$ and $y = 0, 1, 2, \dots, 31$.

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.

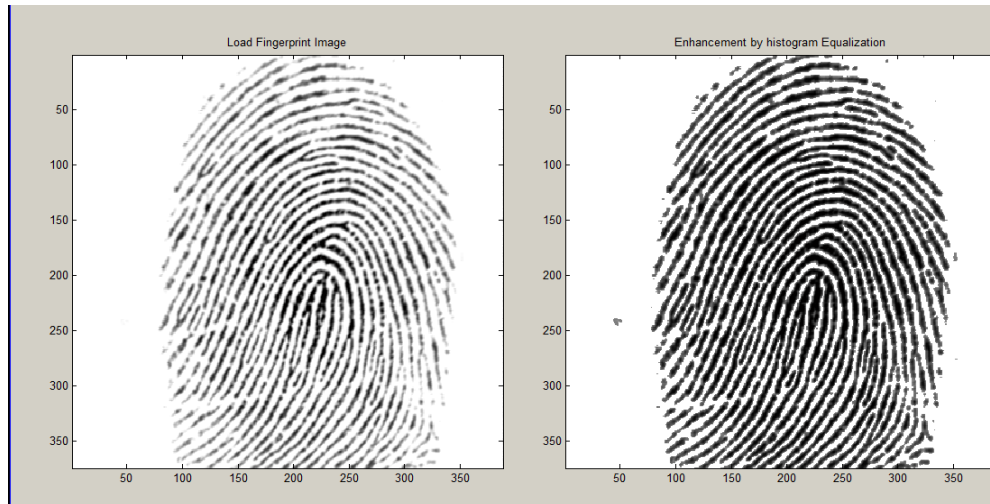


Fig. 4 Histogram Equalization



Fig.5 Fourier Transformed image

iv) Fingerprint Binarization: In this step binarization of above fingerprint is performed typically the two colors used for a binary image are black and white though any two colors can be used. The color used for the object(s) in the image is the foreground color while the rest of the image is the background color. In the document scanning industry this is often referred to as bi-tonal. Binary images are also called *bi-level* or *two-level*. This means that each pixel is stored as a single bit (0 or 1). The names *black-and-white*, *B&W*, *monochrome* or *monochromatic* are often used for this concept, but may also designate any images that have only one sample per pixel, such as grayscale images.

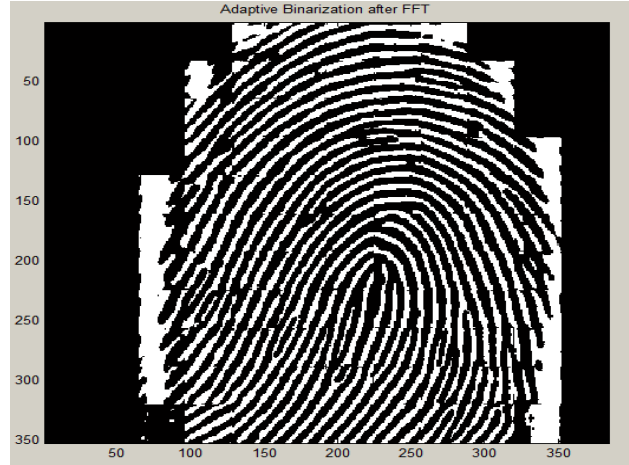


Fig. 6 Binarized Fingerprint

v) Orientation flow Estimation: The next step is calculation of orientation of minutiae's from fingerprint image. Orientation calculation is critical for fingerprint image enhancement and restoration in both frequency and spatial domain. The orientation image represents the local orientation of the ridges and is a matrix of direction vectors. Estimate the block direction for each block of the fingerprint image with $W \times W$ in size (W is 16 pixels by default). The algorithm is:

- i) 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.
- ii) For each block, use Following formula to get the Least Square approximation of the block direction.

$$\tan 2\theta = 2 \sum \sum (g_x * g_y) / \sum \sum (g_x^2 - g_y^2) \quad \text{for all the pixels in each block.}$$

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.

$$\tan 2\theta = 2 \sin \theta \cos \theta / (\cos^2 \theta - \sin^2 \theta)$$

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:

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

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

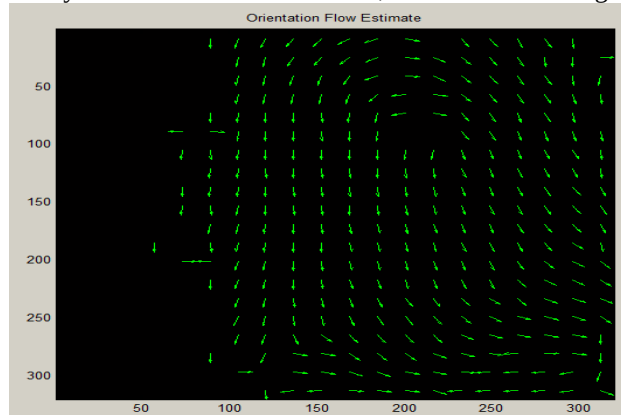


Fig. 7 Orientation Flow Estimate

vi) Thinning: Thinning is a morphological operation that is used to remove selected foreground pixels from binary images. It is used to eliminate the redundant pixels of ridges till the ridges are just one pixel wide. Thinning is normally only applied to binary images, and produces another binary image as output. It is the final step prior to minutiae extraction. It uses an iterative, parallel thinning algorithm. All the pixels on the boundaries of foreground regions that have at least one background neighbor are taken. Any point that has more than one foreground neighbor is deleted as long as doing so does not locally disconnect the region containing that pixel. Iterate until convergence.

Steps of Thinning:

- (i) Sobel operator is applied to reduce the threshold output of the edge detector.
- (i) The image is set at a particular gray level to obtain a binary image.
- (ii) The thinning iteration is applied until all lines are one pixel wide.

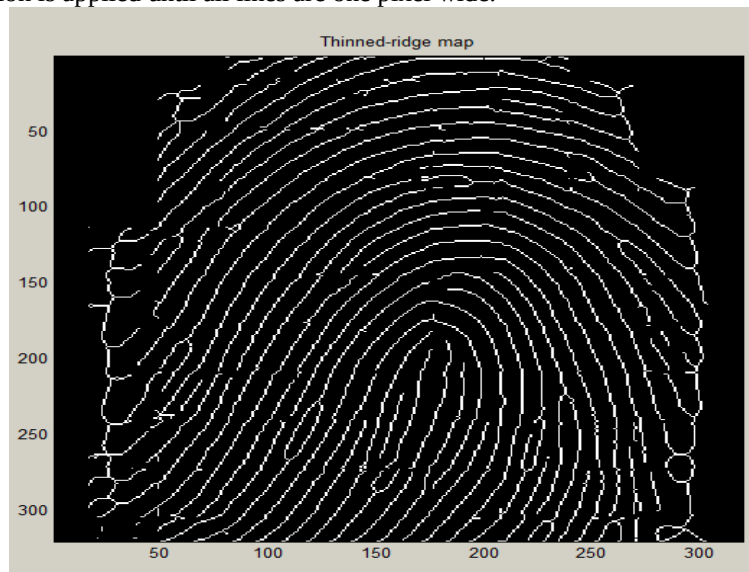


Fig. 8 Image After Thinning

vii) Minutiae extraction: After the enhancement of the fingerprint image the next step is minutiae extraction. The method extracts the minutiae from the enhanced image. This method extracts the ridge endings and bifurcations from the skeleton image by examining the local neighborhood of each ridge pixel using a 3×3 window. The method used for minutiae extraction is the crossing number (CN) method. This method involves the use of the skeleton image where the ridge flow pattern is eight-connected. The minutiae are extracted by scanning the local neighborhood of each ridge pixel in the image using a 3×3 window. CN is defined as half the sum of the differences between the pairs of adjacent pixel. The ridge pixel can be divided into bifurcation, ridge ending and non-minutiae point based on it. A ridge ending point has only one neighbor, a bifurcation point possesses more than two neighbors, and a normal ridge pixel has two neighbors. A CN value of zero refers to an isolated point, value of one to a ridge ending, two to a continuing ridge point, three to a bifurcation point and a CN of four means a crossing point. Minutiae detection in a fingerprint skeleton is implemented by scanning thinned fingerprint and counting the crossing number. Thus the minutiae points can be extracted.

A 3×3 window is used. The CN is given by $CN = 0.5 \sum_{i=1}^8 (P_i - P_{i+1})$ (4.1) For a pixel q, the eight pixels are scanned in an anti-clockwise direction. The pixel can be classified after obtaining its pixel value. The coordinates, orientation of the ridge segment and type of minutiae of each minutiae point is recorded for each minutiae.

After a successful extraction of minutiae, they are stored in a template, which may contain the minutia position (x,y), minutia direction (angle), minutia type (bifurcation or termination), and in some case the minutia quality may be considered. During the enrollment the extracted template are stored in the database and will be used in the matching process as reference template or database template. During the verification or identification, the extracted minutiae are also stored in a template and are used as query template during the matching.

viii) 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. It includes two consecutive stages: one is alignment stage and the second is match stage.

1. 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.

2. 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.

a) Alignment Stage:

1. The ridge associated with each minutia is represented as a series of x-coordinates ($x_1, x_2, \dots, x_n$) 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 $10 \cdot L$.

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

$$S = \sum_{i=0}^m x_i X_i / [\sum_{i=0}^m x_i^2 X_i^2]^{0.5},$$

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:

$$\begin{pmatrix} x_{i_new} \\ y_{i_new} \\ \theta_{i_new} \end{pmatrix} = TM * \begin{pmatrix} (x_i - x) \\ (y_i - y) \\ (\theta_i - \theta) \end{pmatrix},$$

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

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

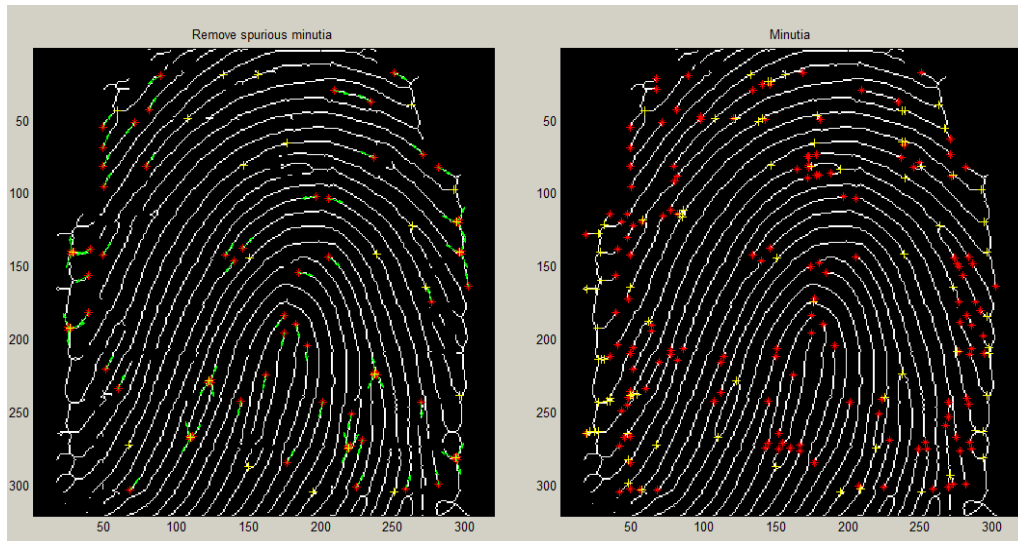


Fig. 9 Minutiae Marking

b) Match Stage:

The matching algorithm for the aligned minutia patterns needs to be elastic since the strict match requiring that all parameters (x, y, θ) are the same for two identical minutia is impossible due to the slight deformations and inexact quantizations of minutia. Our approach to elastically match minutia is achieved 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 minutia 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 is $100 \cdot \text{ratio}$ and ranges from 0 to 100. If the score is larger than a pre-specified threshold, the two fingerprints are from

the same finger. However, the elastic match algorithm has large computation complexity and is vulnerable to spurious minutia.

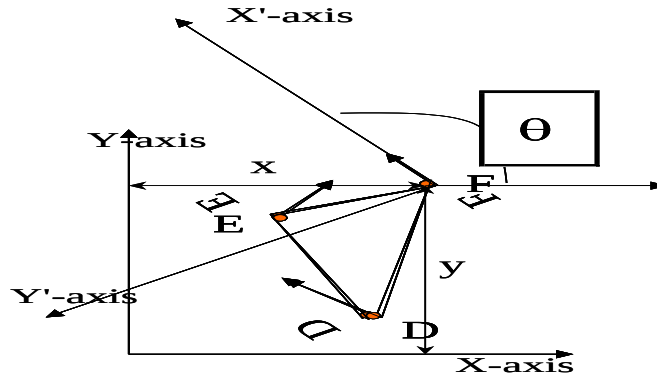


Fig. 10 Effect of translation and rotation

III. Conclusion

In this paper minutia extraction and a minutia matching by phase spectrum analysis have been combined.. Also some novel changes like segmentation using Morphological operations, minutia marking with special considering the triple branch counting, minutia unification by decomposing a branch into three terminations have been applied. This algorithm has been applied to over 100 of fingerprint images and the results were excellent. This algorithm is invariant to transformation, scaling and rotation.

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