A BROAD SURVEY ON FEATURE EXTRACTION METHODS FOR FINGERPRINT IMAGE ANALYSIS

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ABSTRACT

This paper focused on the study of various feature extraction techniques applied for fingerprint identification, verification and classification as it is the most important step for image processing. Feature extraction techniques are classified into local (low level) and global (high level) features. Global features such as arch, loop, delta and whorl where as local features such as ridge end and bifurcation called minutiae are majors of automatic fingerprint recognition system. In this study, it has been observed that most of the fingerprint recognition systems are based on minutiae features. In this paper we analyze the various feature extraction methods used so far with their mathematical background to the readers.

Keywords: Feature extraction, Fingerprint.

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1. INTRODUCTION

Fingerprints have been used as a most reliable personal authentication system in today's digital world as because of stability through life and uniqueness (i.e the set of fingerprints of two persons are not same). A fingerprint pattern consists of ridges and valleys. Fingerprint recognition systems are broadly divided into three steps as (1) pre-processing, (2) extracting relevant features and (3) Pattern identification, or recognition or classification. Feature extraction is the process of reducing a higher dimensionality feature space to a lower dimensionality features to get most relevant information (less data more information) from a pattern. Instead of feeding the whole pattern having much data, but not much information to the further training or matching step, most relevant information should be taken into consideration to reduce the time and space of an algorithm. Feature extraction step basically carried out after pre-processing step where the image pattern was refined and the quality of

image should improved. Feature selection and classification are two phases of feature extraction step that should be done carefully so that in the recognition or pattern classification step it provides the desired output. In case of fingerprint image the features are described in three levels as:

Level 1: Ridge orientation and frequency

Level 2: ridge skeletons

Level 3: outer and inner contours of ridges
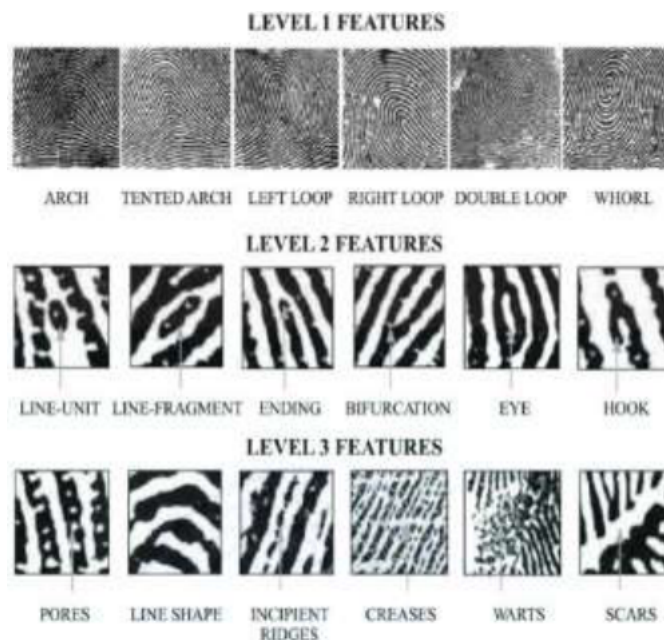
Figure 1 Fingerprint minutiae points at different levels

2. LITERATURE REVIEW

In the field of feature extraction techniques for fingerprint identification, verification and classification, various works have been done so far. In this paper our aim is to introduce these methods to the readers to get the updated information and their working principles till today. Enhancement of the fingerprint is carried out by the directional field, and together with for classification, singular points are used, while the minutiae features are used for matching. Many feature extraction approaches have been proposed for fingerprint pattern recognition and most of these proposed systems are based on local minutiae features. In the following section some papers we have studied are discussed.

Moayer and Fu [1], in this paper, they demonstrate a syntactic approach by using iterative operator (Laplacian) with a thresholding (dynamic) algorithm to binarize the fingerprint images. Verma, M.R., A.K. Majumdar, and B. Chatterjee [2], in this paper, they proposed a fuzzy approach to maintain the number of black and white pixels for each neighbourhood by using a adaptive thresholding. O'Gorman and Nickerson [3], in this paper they proposed filter bank oriented enhancement of fingerprint images with a matrix. The elements of this matrix are the tangent direction to the ridgelines of the corresponding image. It was also suggested to binarization of the image through this method. Sherlock, B.G, D.M. Monro, and K. Millard. [4], proposed a filter of frequency domain by position depended filters for enhancement and binariztion of fingerprint images. Szekely and Szekely [5], in this paper they proposed a fingerprint detection technique based on minutiae points where they computed the divergence of the directional image from binary fingerprint images. In this survey it has been observed that many automated fingerprint recognition systems were

proposed through enhancement of fingerprint images to overcome noise in the fingerprint images and various neural network approaches were proposed to recognise and classification of fingerprint image. Mehtre, B.M., [6], proposed a analysis of noisy fingerprint images with their identification with the system. Weber. D.M [7], in this paper they proposed cost effective frequency domain filtering method for enhancement and binarization of fingerprint images and finds the minutiae by using local thresholds. Leung, M.T., W.E. Engeler, and P. Frank[8], proposed minutiae feature extraction through a multilayer perceptron after applying a bank of Gabor filters. Leung, W.F., S.H. Leung, W.H. Lau, and A. Luk[9], in this paper they proposed a method to extract the minutiae by using a three-layer perceptron from thinned binary fingerprint images. Hung. D.C.D.[10] and Xiao, Q. and H. Raafat [11], in these papers they proposed an algorithm to improve the speed and accuracy of the network from minutiae features by eliminate false minima. Jianjiang Feng and Anil K. Jain et al. [12], in this paper they proposed minutiae based fingerprint matching method that reconstructs the whole fingerprint with few false minutiae. Arun Ross, Jidnya Shah and Anil K. Jain et al. [13], in this paper they proposed n algorithm for reconstructing fingerprint images from minutiae points due to the orientation field of minutiae points. Anil K. Jain, Fellow, IEEE, Yi Chen , IEEE, and Meltem Demirkus, IEEE et al. [14], here they proposed a matching algorithm that uses features of level1, level2 and level3. M. Tico, E. Immonen, P. Ramo, P. Kuosmanen, and J, Saarinen[15], In this paper they proposed a Discrete Wavelet Transform on the cropped fingerprint image and calculated the standard deviations of the DWT coefficient for matching. S. Tachaphetpiboon and T. Amornraksa[16], In their implementation they applied DCT and DWT feature extraction methods for the same sub images and calculated the distribution in frequency and the standard deviations are calculated from nine overlapping regions for recognition. S.Malathi and Dr.C.Meena[17], In this paper they applied Local Binary Pattern (LBP) method. Here they extract pores of fingerprint images by taking window size of 32X32. For matching they measured the distance between two lbp feature histograms. M.P Dale, M.A Joshi, M.K Sahu[18], in this paper they applied Discrete Cosine Transform (DCT) feature extraction directly to the fingerprint images without any pre-processing by dividing into various block and calculating the standard deviations from the feature vectors for matching. C. J. Lee and S. D. Wang[19], proposed a Gabor filter feature extraction method. They used six Gabor filters, (0 ° , 30 ° , 60 ° , 90 ° , 120 ° , 150) anf a frequncy. F=10 to extract the features. Nanni, Loris & Lumini, Alessandra[20], proposed a Local Binary Pattern (LBP) feature extraction method for a hybrid fingerprint matching system by subdividing the image into sub-windows, a segmentation is performed to discard background, then each sub-window is passed through a bankmof Gabor filters and LBP and then matching is done by Euclidean distance between them. Shashi Kumar D R1, K B Raja2, R K Chhotaray3, Sabyasachi Pattanaik[21], proposed a DWT feature based fingerprint recognition system for non minutiae features. They calculated the Dominant local orientation angle θ and Coherence are computed on LL band only and compare with the stored database fingerprint on Euclidean distance method. Yongxu, Wang & Xinyu, Ao & Yuanfeng, Du & Li, Yongping[22], proposed Principal Component Analysis feature extraction method to extract statistical features of fingerprint images. This feature vector is employed to segment of ROI of the fingerprint image. Chhaya Sunil Khandelwal, Ranjan Maheswarib, U. B. Shinde [23], reviewed on PCA and Fisher's LDA on both iris and fingerprint images for authontication of individual by matching these features. Yager N, Amin A[37], proposed a fingerprint classification methods into five major classes, known as Henry classes. These are level-1 features of a gray scale fingerprint image namely loop (left and right), Arch, Whorl, Tented Arch. By taking these features they proposed the matching algorithm. Candela G[39], worked on orientation field information of global and local ridge patterns in fingerprint images. Chong M, Ngee T, Jun L, Gay K[40], worked on Bspline curves representation of ridges and

these curves are used as features for further representation of other steps of matching algorithm.

3. FEATURE EXTRACTION

In this paper, our main aim is to present various feature extraction methods such as FFT, DWT, DCT, PCA, LBP, LPQ, Gabor Filter and their algorithms used so far to the research scholars and readers for better understanding and implementation. In any pattern recognition system, feature selection and classification are the two major steps where feature selection step is more critical since the classifier will not be able to work properly, if feature selection process was not good enough. Then these feature vectors are used in pattern recognition and classification process in further steps. In general if we say feature extraction is the process of extracting precise reduced features from a raw high features image pattern. The importance of feature extraction method is to reduce the dimensionality of an image with reliable and sufficient information for further step of image processing. In this paper we are also providing some methods for feature extraction used in fingerprint images to the readers for their better understanding and in their future research activity in this field.

3.1. Gabor Filter Features

Gabor filters are special types of bandpass filters basically used for texture analysis, edge detection and feature extraction in image processing. In fingerprint feature extraction when Gabor filter is applied, it gives the highest response at edges and at points where texture changes i.e on ridges and furrows. The general form of Gabor filter is given as:

$$g(x, y, f, \theta, \varphi, \sigma, \gamma) = \exp\left(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2}\right) \exp\left(i\left(2\pi\frac{x'}{f} + \varphi\right)\right) \dots (1)$$

Where:

$\sigma < -$ is the standard deviation of the gaussian function

$\theta < -$ is the orientation of the normal to the parallel stripes of the Gabor function

$f < -$ is the frequency of the sinusoidal factor in the equation

$\gamma < -$ is the spatial aspect ratio

$\varphi < -$ is the phase offset

$x' = x \cos\theta + y \sin\theta$ and

$y' = -x \sin\theta + y \cos\theta$

In the above equation, σ(sigma) controls the width of the Gaussian envelop, θ(theta) controls the kind of features of the filter at various angles between 0 to 180 degree, γ(gamma) controls the ellipticity of Gaussian function, φ(psi) that controls the phase offset and f controls the variations on frequencies.

Ksize: is the size of convolution, basically set to a square size (i.e the fingerprint image is divided into nXn non overlapping sub images) and then apply Gabor filter for different θ angles, frequencies and standard deviations. Then the component of the finger is the average absolute deviation of each n X n block of the different filtered images.

3.2. Fast Fourier Transform (FFT)

FFT is a fast algorithm that computes the Discrete Fourier Transform (DFT) by converting the image from spatial domain to frequency domain which reduces the time complexity from N^2 to $N\log_2 N$ of N points. And then apply inverse FFT to the image to reconvert to spatial domain.

First decompose the gray scale fingerprint image into w X w non overlapping sub images, where $f(x,y)$ is the gray value of the fingerprint image f in the block (x,y). Apply FFT to each sub image and calculate the pattern for each class and the result f_block(p,q) of that block in positin (p,q) is given as:

$$f\_block(p,q) = \sum_{x=0}^{w-1}\sum_{y=0}^{w-1} f(x,y) * e^{-j2\pi\left(\frac{xp}{w}+\frac{yq}{w}\right)}.. \qquad (2)$$

Where p, q = 0, 1, 2..., w-1.

To enhance a specific block, we may multiply the FFT with the magnitude, where the magnitude of a block is given by:

FFT = abs(F(p,q)) = |F(p,q)|. And the enhanced block we get is

$$h(x,y) = F^{-1}[F(p,q) * |F(p,q)|^k]$$

and $F^{-1}\big(F(p,q)\big)$ is done by:

$$f(x,y) = \frac{1}{ww}\sum_{x=0}^{w-1}\sum_{y=0}^{w-1} F(p.q) * \exp\left\{j^{2\pi} * \left(\frac{xp}{w} + \frac{yp}{w}\right)\right\} \qquad (3)$$

Where x. y= 0, 1, 2, ... w-1.

Then the direction of the local flow orientation of each block of size w X w is computed which returns ROI of the image.

3.3. Principal Component Analysis (PCA)

PCA is a technique used for identification of a smaller number of uncorrelated variables known as principal components from a larger set of data that still contains the most information in the large set. In fingerprint recognition system it extract meaningful features from high dimensional data in a way that helps us interpret the major trends in our data. It takes the advantage of eigenvector properties for determination of selected object orientation. The steps of PCA feature extraction are as:

- Let there are N input images each of size (K X K), convert each such images in a single vector of form (K.K×1), thus the 2D matrix of all N images be K.K × N denoted as I_N is given as:

$$I_N = \begin{bmatrix} i_1^1 & i_1^2 \cdots & i_1^N \\ \vdots & \ddots & \vdots \\ i_{K*K}^1 & i_{K*K}^2 \cdots & i_{K*K}^N \end{bmatrix} \qquad (4)$$

Where i_x^p is the pth image's x[th] pixel value of dimension K X K.

- Compute the mean of the images I_{mean} and then subtract it from each image to calculate a matrix say A as follows:

$$I_{mean} = \frac{1}{N}\sum_{n=1}^{N} i_k^n \quad \text{for all k= 1,2,... K*K,}$$

Means row wise mean of the above matrix I_N.

A=[$I_N - I_{mean}$]KK * N

- Now compute the covariance matrix, C_A as:

C_A = A*A[T] of dimension KK * KK.

- Calculate the eigenvectors $\{\Omega_1, \Omega_2, \dots, \Omega_N\}$ and eigenvalues$\{\lambda_1, \lambda_2, \dots, \lambda_N\}$ of the covariance matrix and arrange the eigenvectors in descending order of their eigenvalues and take the first M eigenvectors, M < K*K that correspond to the M largest eigenvalue.

- Construct the projection matrix (space of the finger images) W from the selected M eigenvectors and transform the original dataset which is the reduced dimension of M of the original data of dimension K*K.

The eigen fingerprint is given by:

$f_i = [I_N] * \Omega_i$ where Ω_i is the eigenvector   and f_i are the eigen-fingerprint.

3.4. Discrete Wavelet Transform (DWT)

The discrete wavelet transforms transform the time domain signal to a discrete wavelet representation. In case of fingerprint images DWT segmented multi resolution representation. A two level decomposition is applied to fingerprint image, one along with row and the second one along, which results in four distinct bands LL, LH, HL, and HH where L is low pass filter and H is high pass filter. Most of the fingerprint information is concentrated in the LL band; the vertical information of the fingerprint image is obtained by LH band, the horizontal information of the fingerprint image is obtained by HL band and the diagonal details of the fingerprint image is obtained HH band.
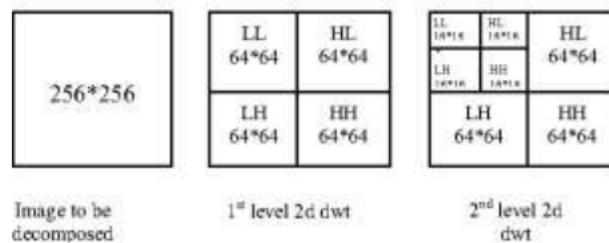
(a)

(b)

Figure 2 (a) DWT sub window image with low and high band filter (b) DWT of fingerprint image

The two dimensional DWT of an image signal requires the 2D filters during the multiplication of separable functions and scaling in n_1(horizontal), n_2(vertical) direction as:

$$\varphi(n_1, n_2) = \varphi(n_1)\varphi(n_2) \qquad (5)$$
$$\psi^H(n_1, n_2) = \psi(n_1)\psi(n_2) \qquad (6)$$
$$\psi^V(n_1, n_2) = \psi(n_1)\psi(n_2) \qquad (7)$$
$$\psi^D(n_1, n_2) = \psi(n_1)\psi(n_2) \qquad (8)$$

Where $\varphi(n_1, n_2), \psi^H(n_1, n_2), \psi^V(n_1, n_2), \psi^D(n_1, n_2)$ represents the signal with horizontal, vertical and diagonal details respectively. And the 2D DWT of an fingerprint image function of size M X N is given as:

$$W_\varphi(j_0, k_1, k_2) = \frac{1}{\sqrt{MN}}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} s(m, n)\varphi_{j_0, k_1, k_2}(m, n). \qquad (9)$$

$$W_\psi^i(j_0, k_1, k_2) = \frac{1}{\sqrt{MN}}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} s(m, n)\psi_{j_0, k_1, k_2}^i(m, n). \qquad (10)$$

where i={H, V, D} indicate the directional index of the wavelet function.

3.5. Discrete Cosine Transform (DCT)

Discrete Cosine Transform is a method that transforms an image in spatial domain to frequency domain by partitioning image pixel matrix in blocks of N X N size.

- DCT convert an image into its equivalent frequency

- domain by partitioning image pixel matrix into blocks of size

- N*N, N depends upon the type of image.

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In frequency domain, the image is decomposed into many frequency components with most of the image information being concentrated in a part of those components. The energy compaction property along with the removal of redundancy are the main reasons, why it is used for images in the frequency domain. The DCT is one of the most popular frequency transformations in image. A 2D DCT for an image I of size N X N is defined as:

$$I(k_1, k_2) = \frac{2}{N} u(k_1) u(k_2) \sum_{n1=0}^{N-1} \sum_{n2=0}^{N-1} i(n_1, n_2) cos \frac{\pi(2n_1 + 1)k_1}{2N} cos \frac{\pi(2n_2 + 1)k_2}{2N} .. (11)$$

Where k_1, k_2=0, 1, 2, ... N-1,

$\mu(0) = \frac{1}{\sqrt{2}}$ and $\mu(k) = 1$ for $n \neq 0$

Hence the 2D DCT can be expressed as:

$$i(k_1, k_2) = \frac{2}{N} \sum_{n1=0}^{N-1} \sum_{n2=0}^{N-1} u(k_1) u(k_2) i(n_1, n_2) cos \frac{\pi(2n_1 + 1)k_1}{2N} cos \frac{\pi(2n_2 + 1)k_2}{2N} ... (12)$$

The basic operation of the DCT is as follows for an image of size N X N:

Let $i(k, l)$ is the intensity of the pixel in k^{th} row and l^{th} column.

$f(u, v)$ is the DCT coefficient in k_1^{th} row and k_2^{th} column of the DCT matrix.

Since much of signal energy in most of images is at low frequencies, those appear in upper left corner of DCT.

And since higher frequencies lies at lower right corner, Feature compression is achieved and are often small.

Basically an 8X8 array is a input to the DCT which contains each pixel's gray scale value of 8 bit from 0 to 255.

3.6. Local Binary Pattern (LBP)

The LBP is a feature extraction method, which labels the pixels of an image to binary number by thresholding the neighbourhood of each pixel. Due to its discriminative power and computational simplicity, LBP is used for texture classification in 2D shaped image. The basic idea of LBP is that the image is subdivided into blocks of size 3X3, then in each block the central pixel value is used as a threshold for its 8 neighbour pixels to binarize the code and the equation of constructing LBP is given as:

$$LBP(i_x, i_y) = \sum_{i=0}^{7} 2^n h\left(I_n - I(i_x, i_y)\right) \qquad (13)$$

Where $LBP(i^x, i^y)$ is the LBP value at centre pixel, I^n and $I(i^x, i^y)$ are the values of neighbour pixel and centre pixel respectively and convert to the gray values of 8 surrounding pixels by function s is defined as:

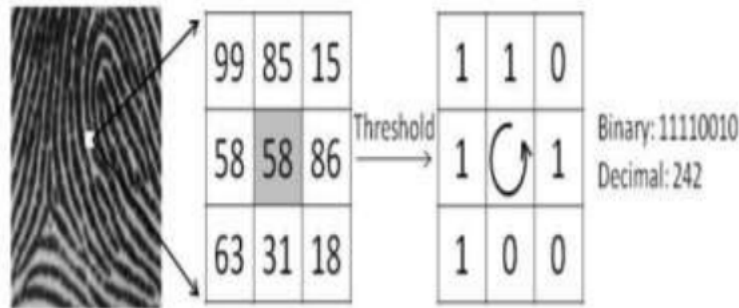$$s(x) = \{1 \ if \ x \geq 0 \ and \ 0 \ if \ x < 0 \qquad (14)$$

Figure 3 LBP 3X3 sub window for binarization

3.7. Minutiae Feature Extraction

The major features of a fingerprint image are minutiae points. In this study it was observed that most work done on two minutiae points 1) ridge ending and 2) ridge bifurcation. A ridge ending is a point that ends abruptly and a bifurcation is a point where it diverges into branches. It also has been said that a quality fingerprint image can have 25-80 minutiae points as per its resolution. Basically a minutiae m_i can be described by four parameters as:

$m_i = (x_i, y_i, \theta_i, t_i)$, Where x_i and y_i are coordinates of the minutiae point, θ_i is the direction from local ridge orientation and t_i is the type of minutiae points (ridge ending, bifurcation etc)
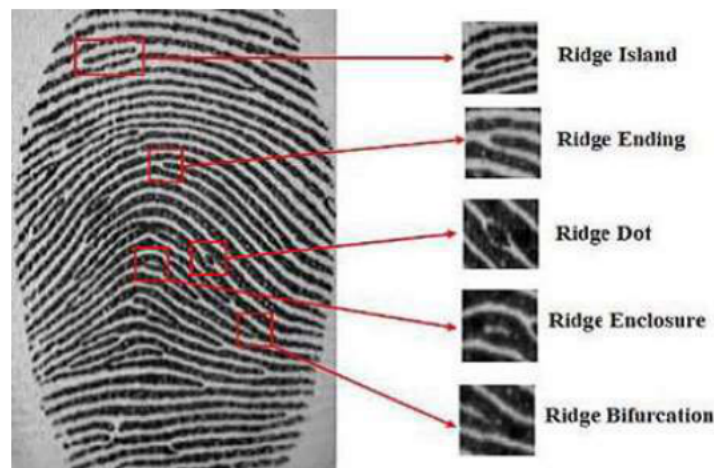

Figure 4 Minutiae features of a fingerprint Image

To find out minutiae points of a fingerprint image, it first goes through binarization and ridge thinning process. Then minutiae are calculated using a 3X3 window size of image by considering local neighbourhood of each pixel of that window. Most of work done for minutiae extraction was through crossing number (CN). The CN value is computed which is described as follows:

Let a 3X3 block of an image with its neighbourhood of each pixel is shown as follows:

P_4	P_3	P_2
P_5	P	P_1
P_6	P_7	P_8

Figure 5: A 3X3 block image for minutiae Crossing Number

Then the crossing number is computed as:

$$CN_{(x,y)} = \frac{1}{2}\sum_{i=1}^{8}|p_i - p_{i+1}|, \quad p_1 = p_9 \qquad (15)$$

It is defined as half the sum of the differences between adjacent pixel pairs in the eight-neighbourhood. From the properties of the crossing number one can classify a ridge pixel as an ending, bifurcation or non-minutiae point as shown in following table.

Table 1: Properties of Crossing Number

CN	PROPERTY
0	Isolated Point
1	Ridge Ending Point
2	Continuing ridge Point
3	Bifurcation Point
4	Crossing Point

4. CONCLUSIONS

The main objective of our survey is to introduce various feature extraction methods used for fingerprint image pattern to readers and researchers. Basically these feature extraction methods are used to reduce the dimensionality of the original image from a larger feature dataset to a smaller feature dataset. It has also been observed that the feature extraction methods were chosen to keep the most valuable features and discard the least reliable features of image for better identification, recognition and classification.

Many feature extraction techniques have been developed so far are discussed here in our survey. In this survey, we also discussed which feature extraction method will be better for the real world dataset, depending upon the requirement and application to be used. Here we present an overview of the recent feature extraction algorithms proposed so far in literature. This study also discuss the steps of various feature extraction methods by which one can choose the appropriate method for the further phases of fingerprint image identification, recognition and classification.

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