A DoG based Approach for Fingerprint Image Enhancement

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A DoG based Approach for Fingerprint Image Enhancement

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Certificate

This is to certify that the work in the thesis entitled ***A DoG based Approach for Fingerprint Image Enhancement*** by ***Shila Samantaray*** is a record of an original research work carried out under our supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology in Computer Science and Engineering. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

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"God, who foresaw your tribulation, has specially armed you to go through it, not without pain but without stain."

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Shila Samantaray

Abstract

Fingerprints have been the most accepted tool for personal identification since many decades. It is also an invaluable tool for law enforcement and forensics for over a century, motivating the research in Automated fingerprint-based identification, an application of biometric system. The matching or identification accuracy using fingerprints has been shown to be very high. The theory on the uniqueness of fingerprint minutiae leads to the steps in studying the statistics of extracting the minutiae features reliably.

Fingerprint images obtained through various sources are rarely of perfect quality. They may be degraded or noisy due to variations in skin or poor scanning technique or due to poor impression condition. Hence enhancement techniques are applied on fingerprint images prior to the minutiae point extraction to get sure of less spurious and more accurate minutiae points from the reliable minutiae location.

This thesis focuses on fingerprint image enhancement techniques through histogram equalization applied locally on the degraded image. The proposed work is based on the Laplacian pyramid framework that decomposes the input image into a number of band-pass images to improve the local contrast, as well as the local edge information. The resultant image is passed through the regular methodologies of fingerprint, like ridge orientation, ridge frequency calculation, filtering, binarization and finally the morphological operation thinning. Experiments using different texture of images are conducted to enhance the images and to show a comparative result in terms of number of minutiae extracted from them along with the spurious and actual number existing in each enhanced image. Experimental results out performs well to overcome the counterpart of enhancement technique.

Contents

List of Figures

List of Tables

List of Algorithms

Chapter 1

Introduction

Fingerprint being the oldest and easily available trait of biometrics, offers an infalliable means of personal identification. The science of fingerprint identification stands out among all other forensic sciences for many reasons and which let the first forensic proffessional organization, the International Association of Identification(IAI) to establish in the year 1915. Biometric is a method for uniquely recognizing individuals, which is based on one or more inherent physiological or behavioral property of the subject. The method is much accepted as compered to the traditional token - based or knowledge - based method involving ID- cards, PIN numbers, SSN etc. The reasons behind acceptance of biometric for personal identification/authentication are :

- the physical presence of the subject is required to get itself identified/authenticated
- The personal identity cannot be stolen, lost, forgotten, shared, or hacked.

1.1 Biometric Identification and Fingerprint

Biometric identification system is a user authentication/verification management system utilizing fully/semi-automated schemes to recognize subjects individualy based on their biological characteristics. Depending upon the accuracy and performance of the biometric system it can be used as :

- considering either of the physiological or behavioral biomertric characteristics, known as a unimodal biometric system OR

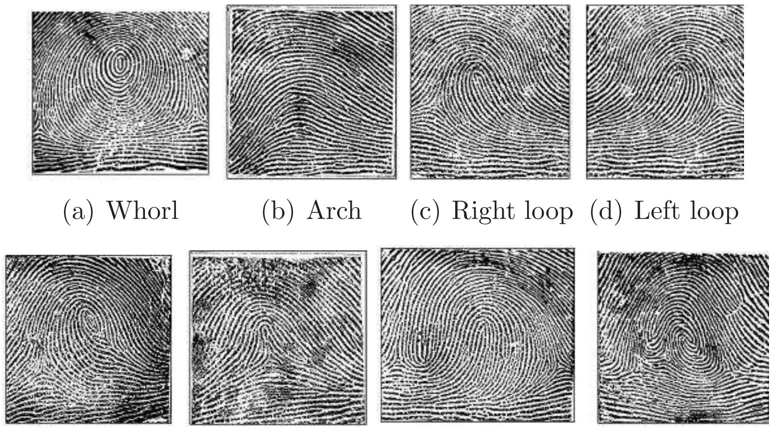
- considering a combination of more than one physiological and/or behavioral biometric characteristics, known as a multimodal biometric system for enrolment /verification/identification of any subject.

Being a pattern recognition system the biometric system measures and analyses human physiological characteristics such as fingerprint, iris, ear pattern, voice pattern and behavioural characteristics like gait pattern etc.

Among the available physiological biometric traits some of the traits outperform others. The human race have used fingerprints for personal identification since many decades. The matching accuracy using fingerprints has been shown to be very high as compared to other existing biometric traits [1]. Unlike face and voice patterns, fingerprints are persistent with age and can not be easily disguised. Again, the trait is popular because of their easy access, available low price of fingerprint sensors those are used to acquire image, non intrusive scanning and relatively good performance. In recent years the automatic fingerprint recognition systems has dragged special attention through significant improvements in its performances. Therefore, fingerprint is one of the most researched and matured field of biometric authentication.

It is believed that the first known example of biometrics in practice was a form of fingerprinting being used in china in the 14th century, as reported by explorer Joao de Barros [2]. in 1880, Dr. Henry Faulds published an article in the Scientific Journal, 'Nature' (nature). He discussed fingerprints as a means of personal identification, and the use of printers ink as a method for obtaining such fingerprints. In 1882 Bertillon [3] for the first time devised a system of classification known as Anthropometry, which measures the parts of the body as the primary means of identification for judicial identity. He later introduced and included fingerprints for the judicial identification.

Fingerprints are incomperably the most sure and unchanging form of all other forms of signature [4]. A fingerprint is constituted by a set of ridge lines which often run parallel, sometimes terminates and sometimes intersects. The points where the ridge lines terminate or fork are called the manutiae [5] where as according to Galton, each ridge is characterized by numerous minute picularities called minutiae, which may devide and almost immediately reunite, enclosing a small circular or elliptical space or sometimes the independent beginning or ending of ridges. Lastly, the ridge pattern of the fingerprint image may be so short so as to form a small island even. Later Edward Henry(1850 - 1931) [6] refined Galton's classification by increasing the number of classes of fingerprint image. Most of all classification schemes currently used by the policy agencies are variants of Henry's classification scheme. The scheme adopted by FBI defines 3 major classes and 8 sub classes as shown in Figure 1.1



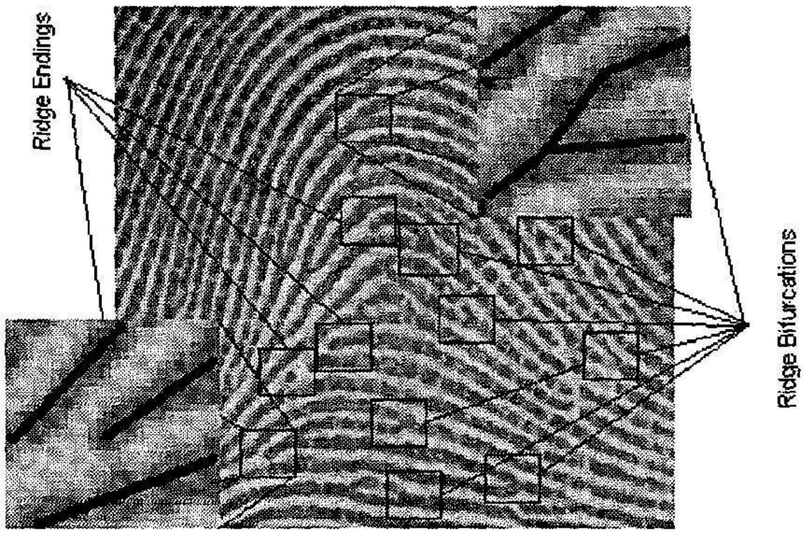
(a) Whorl (b) Arch (c) Right loop (d) Left loop

(e) Central Pocket (f) Tented arch (g) Twin loop (h) Accidental

Figure 1.1: Henry's Fingerprint Classification

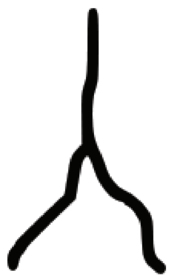
A fingerprint is the pattern of interleaved ridges and valleys on the surface of a fingertip whose formation is determined during the first seven months of fetal development. It has been empiricaly determined that the fingerprints of identical twins are different and so are the prints of each finger of the same person [1]. A genetic code in DNA gives general instructions on the way skin should form in a developing fetus,but the specific way it forms is a result of random events (i.e the exact position of the fetus in the womb at a particular moment and the exact composition and density of surrounding amniotic fluid). This is the reason behind the difference in fingerprint even in identical twins case [7]. The fingerprints are fully stable at about seven months of fetus development and finger ridge configuration do not change throughout the life of an individual, except in case of accidents such as cuts on the fingerprint etc. [8].

Sir Francis Galton conducted an extensive study on fingerprints and introduced the minutiae features for fingerprint matching in 1888. The two most prominent ridge characteristics, called minutia points, are ridge endings and ridge bifurcations [9]. Figure 1.2 illustrates the example of fingerprint with its ridge ending and ridge bifurcation patterns. In a fingerprint image ridges are dark whereas valleys are bright. Ridges and valleys often run in parallel; sometimes they bifurcate and sometimes they terminate.



(a) Fingerprint with Ridge ending and Bifurcation

(b) Ridge Pattern



(c) Ridge Bifurcation

Figure 1.2: Fingerprint Image showing Ridge ending and Bifurcation

A minutiae based fingerprint identification system approaches towards extraction of the ridge patterns correctly. A good quality fingetrprint contains 25-80 number of minutiae [10] depending on the sensor resolution and finger placement on the sensor. However the latent fingerprints or the fingerprint image captured through poor scanners, are found to have fewer number of minutiae points. In order to ensure the minutiae extraction procedure to be a healthy one, the system must have good quality of fingerprint images as input, and this gives a reason to the fingerrpint images for enhancement.

1.2 Thesis Organization

Rest of the thesis presents a better performance to minutiae based fingerprint image enhancement. Chapter 2 provides the literature review, describing the need for fingerprint image enhancement, defining the problem statement of the thesis. Chapter 3 presents the methodology and implementation of a series of techniques on fingerprint image for enhancement. Provides discussions on minutiae extraction technique and experimental results subsequently. Chapetr 4 provides concluding comments including the future extensions those can be made to the project.

Chapter 2

Fingerprint Image Enhancement

2.1 Need for enhancement

The fingerprint images are rarely of perfect quality, due to the reasons like variations in impression condition, skin condition, scanning devices or may be due to non co-operative attitude of the subject. This degraded quality of image can result in a significant number of spurious minutiae being created and genuine minutiae being ignored. A vital step in studying the statistics of fingerprint minutiae is to reliably extract the minutiae feature from fingerprint images. Thus it is important to employ image enhancement techniques prior to minutiae extraction to obtain a good number of reliable estimate of minutiae locations.

The main objective of fingerprint image enhancement is to improve the ridge characteristics of the image, as these ridges carry the information of characteristics features required for minutiae extraction. Ideally, in an well-defined fingerprint image, the ridges and valleys should alternate and flow in a locally costant direction. This regularities facilitates the detection of ridges and consequently allow minutiae to be precisely extracted from the thinned ridges [11]. Thus, the corruption or noise has to be reduced through image enhancement techniques to get enhanced definition of ridges against valleys in the fingerprint images.

2.2 Literature Review

Variours researchers have contributed to the area of fingerprint image enhancement. As in the previous section the need of enhancement is been discussed, still these identification system is popular because of its inherent ease in image acquisition, the numerous sources been available for collection of data to create a strong database of fingerprint images and their established use and collection by law enforcement for personal identification and verification of the subject.

Usage of fingerprints in identifying individuals has been in practice since the late nineteenth century, when sir Francis Galton defined some of the characteristics from which fingerprints can be used for identification. These "Galton points" are the foundation for the science of fingerprint identification, which has expanded and transitioned over the past century.

Fingerprint identification began its transition to automation in the late 1960s along with emergence of computing technologies. With the advent of computers, a subset of Galton points, refered to as minutiae, has been utilized to develop automated fingerprint technology.

In the year 1998 Lin Hong et al.[9] have proposed a fast fingerprint enhancement algorithm. The algorithm improves the ridge valley structure based on estimated local ridge orientation and frequency. The performance of image enhancement algorithm uses the goodness index value for the minutiae calculation and verification. The disadvantage lied with the proposed technique is that it fails in case of noisy images.

In the year 2000 Greenberg et al. [12] proposed two methods for fingerprint enhancement. The first method is carried out with local histogram equalization, Wiener filtering and image binarization. The second method use an unique anisotropic filter for direct grayscale enhancement. Results of the technique worked better for enhancement and the average error percentage in terms of dropped and false minutiae produced, by the proposed approach are considerably lower. The modified Gabor filter approach(that has considered the new parameters for standard deviation) works better for poor quality images with corrupted ridges and blocks.

In the year 2002 Yuliang He et al. [13] proposed a different technique for orientation estimation to the fingerprint image where the ridge orientation direction of a pixel is divided in 8 directions. The ridge direction of each pixel value of those 8 directions, have been applied with a 9×9 window with the pixel at the center.

During the binarization phase, direct binarization of the image with its orientation field is applied instead of binarization by means of global thresholding. The minutia matching algorithm in this paper is originated from Jain et al. [9] but it is done using three steps, those are like,

- is to align the ridges,
- the ridge information to be introduced in to matching process,
- instead of a fixed size bounding box, here a variable size bounding box is proposed for fingerprint matching process.

In 2003 R.Thai [11] in his thesis work showed three additional stages added to the already existing enhancement methodology of Hong et al. [9]. Those stages are segmentation, binarization and thinning. During segmentation he used a method based on variance thresholding to separate the foreground region of the image from the background regions. The binarization is employed considering the global threshold value and the thinning process is performed using 2 iterations via MATLAB operation 'thin' and the MATLAB function 'bwmorph'. Minutiae extraction is done by crossing number method. D.Maltoni et al. [14]in the same year have proposed a mean and standard deviation of the fingerprint image to extract region of interest which has the advantage of ease in calculation. The disadvantage lied as, it does not chop edges very well and even does not work well on too dry or too wet fingers.

In the year 2004 Sen Wang and Yangsheng Wang [15] approached for bandpass filters to remove the undesired noise in the fingerprint images. It has the disadvantage that it concentrates only on the singular point of the image. In the same year Chaohong Wu et al. [16] have applied an integration of anisotropic filter and directional median filter(DMF) to enhance the fingerprint images as Gaussian-distributed noise are reduced effectively by anisotropic filters and impulsive noise are reduced by DMF. The proposed scheme has advantages like, features of ridge boundaries became more smooth, broken ridges are joined perfectly, the holes in the ridges are completely removed. The disadvantages with the approache are like pores of fingerprint ridges are completely removed which originaly lied in input fingerprint image, the anisotropic filter parameters and the window length are set empiricaly and exhibits failure when applied on heavily noisy images and orientation calculation also fails for those regions on fingerprint.

In the year 2006 S. Chikkerur et al. [17] introduces a new approach for fingerprint enhancement based on short time fourier transform(STFT) analysis and the result of the method is dependent on the choice of the window(i.e a 12×12 window) for resolving the properties of the images both in space and frequency. During enhancement in the first phase the author has applied a raised cosine window that outlines the image and is responsible for computing all the intrinsic images(i.e the images those represent the important properties of the fingerprint image as a pixel map of fingerprint) and in the second phase the image is divided in overlapping windows and a band-pass butterworth filter is applied on each window to reconstruct the enhanced image by tiling the results of enhancement of each local window. After enhancement the relative improvement of 17% in the fingerprint recognition rate is observed.

In the year 2007 Xi-Feng Tong et al. [18] proposed a two level convolution template, which is designed according to ridge direction and a simplified convolution is used to enhance fingerprint image. The proposed algorithm runs faster considering the time complexity factor and shows better result than the Gabor filter based enhancement(i.e EER of proposed algorithm is 0.0344 where Gabor filter based ehnacement has EER of 0.0356). In the same year S. A. Sudiro et al. [19] proposed an approach for fingerprint images to detect munitiae, which considers valleys instead of ridges and the approach is based on crossing number algorithm. The algorithm takes lesser time for computation and the number of minutiae points are closer to the actual number of minutiae existing in the finger print image. The disadvantage lying with the technique is that it has a poor thinning process.

In 2008 M.Sepasian et al. [20] proposed a contrast limited adaptive histogram equalization(CLAHE) method instead of histogram equalization based enhancement on the fingerprint images. They have also aproached for an adaptive binarization method. Previously in binarization an unique threshold value is set localy for general fingerprint image analysis but they vary in terms of contrast and intensity. According to the proposed technique thinning is done by using an initial slide neighborhood process to eleminate the development of false information in fingerprint image and the resulting image is produced only in one step, with out any intermediate filtering and consequently with less computational complexity.

In the year 2009 Ibrahim et al. [21] have proposed a directional gaussiaan filter for smoothing purpose. Directional analysis is performed by the Non-Subsampled Contourlet Transform(NSCT) on the smoothed image and then directional energies are used for the reconstruction of enhanced image. Basically the NSCT, is based on the concept of Non-Subsampled Laplacian Pyramid and Decimation-Free Directional Filter Banks (DDFB), also known as Non-Subsampled Directional Filter Banks. Non-Subsampled Laplacian Pyramid is used to decompose the image into low-pass and highpass. Then the Non-Subsampled Directional Filter Bank is applied only to the high-pass images to further decompose the frequency spectrum. The enhanced image is the result of summation of the resultant images from 3 stages of NSCT, where maximum energy on each pixel of the image is calculated.

In the year 2010 Mao et al. [22] proposed a convenient way for fingerprint ridge orientation calculation. Along with that a modified Gabor filter based filtering is applied to compute ridge orientation and ridge frequency. Here the Gabotr filter need to compute a quarter of the original filtering calculation. Hence the fingerprint enhancement technique guarantees on lesser time consumption(i.e in seconds) and expenses too.

2.3 Problem Statement

It can be fairly observed from the literature survey that a number of approaches have been taken to enhance the fingerprint images at various steps of enhancement which comprises of normalization,ridge orientation estimation,ridge frequency estimation,region of interest extraction,filtering and the following steps like binarization,morphological thinning and final step that is minutiae point detection and matching.

some of the literatures follow different filtering techniques or different image enhancement techniques on the fingerprint images showing good results at the described steps of enhancement and finaly the out put interms of more number of accurate minutiae points over falsly detected minutiae points.

It is observed that amongst the enhancement techniques histiogram based equalization method is used in various modified ways representing the contrast enhancement providing the best visual performance in certain conditions but sometimes shows the fatal flaw of over enhancement.

Keeping the shortcomings in view the current research is on the scope of improvements on the histogram equalization based enhancment for fingerprint images to detect correct number of minutiae points comparing to the existing enhancemnt techniques.In the thesis emphasis has been given on the way of implementation of enhancement technique i.e instead of applying the enhancement algorithm directly on the input image , the technique transforms the input image and decomposes it in to number of band-pass images.Then the Gaussian low-pass filtering is applied to obtain laplacian images from the decomposed images.Finaly the reconstruction is done considering the highest decomposed layer of image and the output images of decomposed images applied with diference of Gaussian.The enhancement is followed by the binarisation and thinning methods to prepare the fingerprint images for minutiae extraction phase.

Chapter 3

Proposed Enhancement Technique

3.1 Enhancement and AFIS

The driving force behind the advancement in fingerprint technology are the Forensics and Law enforcement agencies. Using the fingerprints taken at a crime scene has always been a crucial step during criminal investigation. The Law and Administration of several countries heavily relies on automated systems. Hence Automated Fingerprint Identification System, being one of the prime suspect identification iniciative, strongly defines its problem area, investigated as:

- digital fingerprint acquisition,
- local ridge feature extraction,
- ridge characteristics pattern matching.

The operational productivity of the automated fingerprint identification system has boosted the individual areas of fingerprint identification system to give better performance on defined problem areas.

Fingerprint image does not comeout to be a perfect image for direct processings to be applied on them like, ridge feature extraction and pattern analysis. It needs certain preeprocessings to be good enough for remaining part of identification mechanisms. Thus the fingerprint image after aquisition needs to go through an enhancement phase.

3.2 Proposed HE Based Enhancement

A reliable extraction algorithm is a critical step for a general fingerprint identification system. This performance is relatively dependent on the fingerprint image quality and enhancement step, that can improve the clarity of the ridge structures. An Histogram equalization based image enhancement algorithm is proposed. Histogram Equalization is the representative method for contrast enhancement, specificaly global contrast. Along with Histogram Equalization a pyramid based Gaussian filtering is applied. The reconstruction of the final out image which is a combination of both processing [23], aims to get the resultant image, enhanced with local information, such as local contrast and fine edges in the image. The proposed scheme is based on the following eqn as,

$$I_0 = I_N + \sum_{n=1}^{N} D_n \tag{3.1}$$

where I_0 =input grayscale image, I_N = decomposed images with Gaussian low pass filter N = the highest decomposition layer D_n = Laplacian images

3.3 Methodology

This section deals with the methods for constructing a series of processing technique to extract fingerprint minutiae. The algorithm that is manipulated is based on the techniques developed by Hong et al. [9]. The algorithm has basic steps like,

- normalization
- orientation estimation
- ridge frequency estimation
- Gabor filtering
- Binarization
- Thinning

An image enhancement algorithm is proposed to the input fingerprint image prior to the processings for minutiae extraction. That step is a DoG based enhancement technique. All the steps along with the modified steps are explaind in this section.

3.3.1 DoG based Approach

The first step for processing is a DoG based image enhancement approach. The algorithm has two subsections. First section deals with the enhancement of the band-pass image of higher order when the original input is ment to pass through the Gaussian filter. And the second part enhances the difference of Gaussian (DoG) images. The enhanced image is a result of both subsections.

First section of Proposed algorithm is explained in algorithm 3.1. The algorithm at its first step applies, a histogram on the input image to see the luminance range of the image. A smoothing with the Gaussian filter is applied to have a distinguish between ridges and valleys then. By applying Boosting to the whole smoothed histogram, we can track the peaks and valleys correctly. Boosting contributes a quantum jump for the bins of Histigram. Now to suppress the quantum jump in the luminance level of the Histogram, clipping is applied. A global clipping that clips those areas which are above the half of the peak and a local clipping that clips slant wise, the areas below half of the peak. And then the residuals of clipings are distributed among whole bins of Histigram. Finally the contrast enhanced image is the mapping functionof input image and the residual maaped to grey scale.

Second section of the proposed algorithm 3.2.This section does the detail enhancement to overcome the inherent lacunas of HE based enhancement. Apart from contrast enhancement the detail edge enhancement is coverd. Here an adaptive gain function f_n^1 is derived from the luminance values of low pass images I_n. Another noise reduction function f_n^2, performing like a filter, that cuts of small signal of D_n. Here the noise is not an impulsive noise. It is rather the residual noise remaining from the processed or unprocessed image, caused by adaptive gain function. Detail enhancement results out to be the multipication of f_n^1 and f_n^2, applied with a 5×5 Gaussian mask. The final enhanced image I'_0 is the reconstruction as shown in algorithm 3.3 of I'_N and D'.

3.3.2 Normalization

The next processing step is image normalization. Normalization is applied to standardize the intensity value of the image to a prespecified mean and variance. Let the input grey level image be $I(i, j)$, and the normalized image be $N(i, j)$, then the normalized image can be defined as,

$$N(i,j) = \begin{cases} M_0 + \sqrt{\frac{V_0(I(i,j)-M)^2}{V}} & \text{if} I(i,j) > M \\ M_0 - \sqrt{\frac{V_0(I(i,j)-M)^2}{V}} & \text{otherwise} \end{cases} \tag{3.2}$$

where M, V are the estimated mean and variancr on input grey level image. And M_0, V_0 are the desires mean and variance respectively.

3.3.3 Orientation Estimation

The normalized image is taken to calculate the ridge orientation. The orientation calculation is important so as to apply the gabor filtering on the oriented fields, to get maximum response over the ridges at specific orientation.

1. A pixel-wise orientation is estimated, by putting a $W \times W$ size block at the center pixel of normalized image.

2. For each pixel gradient magnitude is calculated as $\partial_x(i, j)$ and $\partial_y(i, j)$, along x and y directions respectively.

3. The orientation at each pixel is given by,

$$V_x(i,j) = \sum_{u=i-\frac{W}{2}}^{i+\frac{W}{2}} \sum_{v=j-\frac{W}{2}}^{j+\frac{W}{2}} 2\partial_x(u,v)\partial_y(u,v), \tag{3.3}$$

$$V_y(i,j) = \sum_{u=i-\frac{W}{2}}^{i+\frac{W}{2}} \sum_{v=j-\frac{W}{2}}^{j+\frac{W}{2}} \partial_x^2(u,v)\partial_y^2(u,v), \tag{3.4}$$

$$\Theta(i,j) = \frac{1}{2} tann^{-1} \frac{V_y(i,j)}{V - x(i,j)}, \tag{3.5}$$

where $\Theta(i, j)$ is the least meansquare estimate of the local orientation at each block of centered pixel.

4. Smoothing the orientation field with Gaussian filter gives the final result of the orientation estimation.

3.3.4 Ridge Frequency Estimation

The local frequency of the ridges are calculated for fingerprint images.The normalized image is divided in to block size $W \times W$. The gray level values of all pixels are projected inside each block along the orthogonal direction to the local orientation. The projection is a sinusoidal wave form, which is again pass through a Gaussian filter to be smoothed. The ridge spacing $RS(i,j)$ is then computed by counting the number of pixels between the minutiae points in the projected wave form and the equation for ridge frequency $RF(i,j)$ is given by,

$$RF(i,j) = \frac{1}{RS(i,j)} \tag{3.6}$$

The ridge continuity only gives a smooth ridge frequency but the discontinuity(i.e the existance of ridge termination or bifurcations), where minutiae points appear in the block, it doesnt produce a well-defined sunusoidal wave form. Such cases are interpolated using the values from the neighboring blocks those have well defined frequency.

3.3.5 Gabor Filtering

The Two-dimensional Gabor filter is a linear filter, consisting of a sinusoidal wave of particular orientation and frequency,modulated by Gaussian envelop. The Gabor filters have both the frequency selective and orientation selective properties. An even symmetry Gabor filter in the spatial domain is defined as,

$$G(x,y,\theta,f) = \exp\{\frac{-1}{2}[\frac{x_\theta^2}{\sigma_x^2} + \frac{y_\theta^2}{\sigma_y^2}]\}cos(2\Pi f x_\theta), \tag{3.7}$$

$$x_\theta = xcos\theta + ysin\theta \tag{3.8}$$

$$y_\theta = -xsin\theta + ycos\theta \tag{3.9}$$

Where θ os the orientation of the Gabor filter, f is the frequency of the cosine wave, $\sigma_x$and σ_y are the standard deviation along x and y axes for the Gaussian envelop. x_θ and y_θ defines the x and y axes of the filter. The ridge orientation and ridge frequencies are already been calculated, and applying the even symmetry gabor filter again gives enhanced ridges in the orientation direction effectively preserving the ridge structure. σ_x determines the degree of contrast enhancement and σ_y determines the smoothing of ridges. A large value will result blurring in the image, where as a low value may not be effective in removing the noise from the image. Hence the σ_x and σ_y has to be set carefully.

3.3.6 Binarization

The process to convert the gray level image to binary images, is binarization. It is done to increase the contrast between the ridge and valley and hence facilitates the extraction of minutiae. The global threshold for binarization is zero. The binarization process checks if the enhanced gay-level image has the pixel value more than zero, then the pixel value is set toa binary value one; otherwise zero. The resulting image of binarization has only two values of pixels i.e one or zero.

3.3.7 Thinning

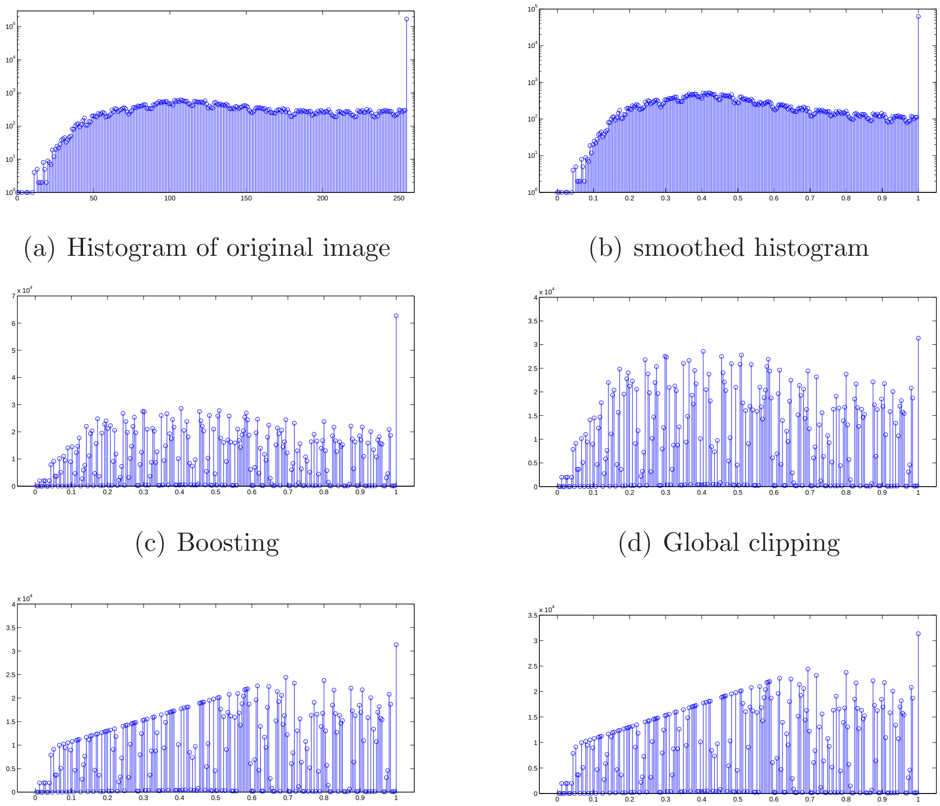
thinning is the morphological operation that erodes out the ridge pixels till they are one pixel wide. The input and the out put, both results binary image only. Thinning preserves the continuity of the enhanced ridge structure, performing the iterative operation till it makes the ridge one pixel wide.. In each iteration the neighborhood of the pixel is considered and a set of pixel deletion criteria are applied to obtain the skeleton of the enhanced fingerprint image.

3.4 Experimental Results

The experiments are performed on implemented MATLAB R2008a on the WIDOWS XP Professional version 2002 operating system. The system configuration is Pentium 4-3GHz with 1.99GB of RAM. The aim of implementing enhancement algorithm is to achieve better result in terms of enhanced fingerprint image, which is measured by number of minutiae points acheived. The database used for experiment is .

3.4.1 DoG based Approach

Figure3.1 explains the first section of the proposed enhancement algorithm. Here the step wise implementation of the algorithm 3.1 and the subsequent enhancement in terms of graph is been produced. Figure 3.6 explains the result of the proposed enhancement scheme. The resulting figure combines the output of contrast enhancement and the detail enhancement as described in algorithm 3.2. The HE based methods demerits were lying with the quantum jump of luminance values in the pixel, which is modified in the proposed scheme by applying the clipping technique during first section. The second section enhance the fine edges and reduce the noise that is added to the image during adaptive gain function.



(a) Histogram of original image
(b) smoothed histogram
(c) Boosting
(d) Global clipping
(e) Local clipping
(f) Redistribution of residuals

Figure 3.1: A contrast Enhancement flow of the input image as per the first section of the proposed method

A distinguishable result can be observed between the original input histogram and the contrast enhanced image.

3.4.2 Normalization

Imges obtained from the DoG based approach are then normalized. Each detail enhanced image is normalized to obtain a normalized image with a prespecified mean and variance for all images. Figure 3.2 shows the ridge enhanced image after the normalization.

(a) Original Fingerprint input image

(b) Normalized image

Figure 3.2: The Results of Fingerprint Image Normalization

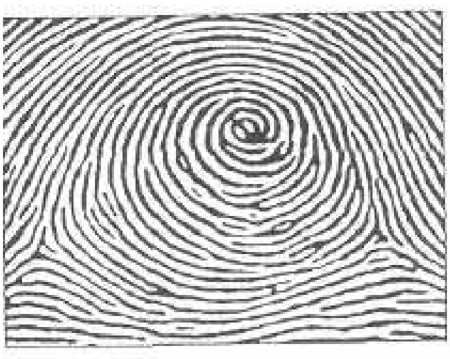
3.4.3 Orientation Estimation

To get a smooth orientation through Gabor filter, the normalized images need to applied with ridge orientation filter. A set of original input images, along with the different pattern of fingerrprint images, are considered for orientation calculation. It can be obeserved, how well the ridge filter has calculated the flow pattern of the ridges, even though there exist invisible flow of patterns. The ridge frequency is also an important factor to be considered before Gabor filtering. Figure 3.3 shows the orientation field on the normalized image.

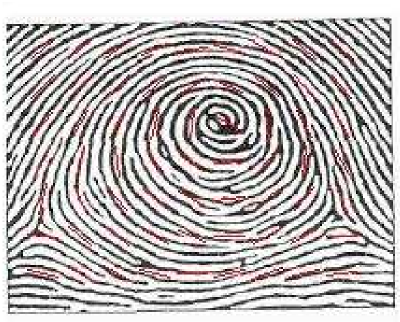
(a) Original Fingerprint input image

(b) Image with Ridge Orientation

(c) Input Fingerprint image with Ridge Frequency



(d) Whorl pattern inputiage



(e) Whorl Pattern with Ridge Orientation

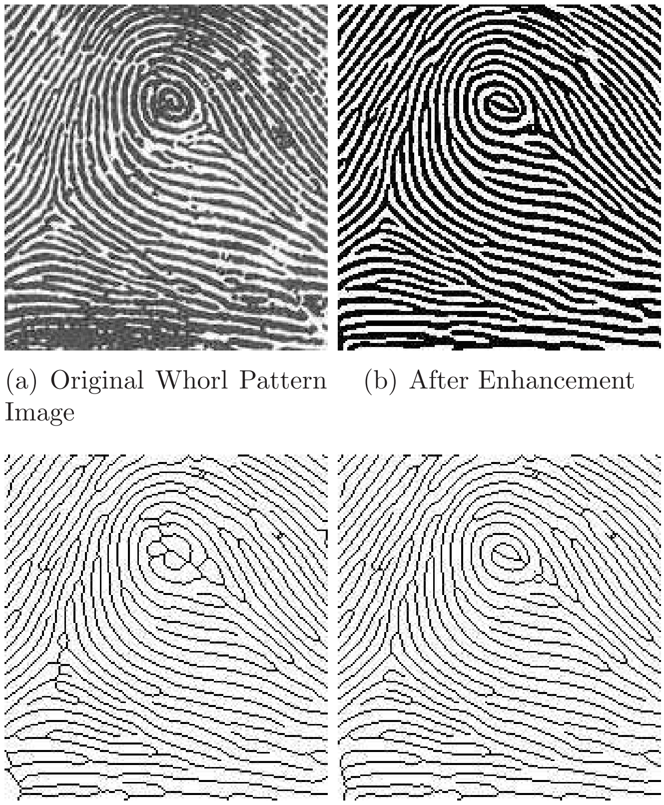
Figure 3.3: The Results of Fingerprint Image Ridge Orientation and Ridge Frequency Estimation

3.4.4 Gabor Filtering

The center part of image processing is, Gabor filtering which redefines the ridge orientations and ridge frequency, those are calculated priorly. The purpose of filtering stage is to enhance the clarity of the ridge structures, reducing the noise. The filter preserves the flow of ridge and valley structure. The filter may not show better performance during enhancement of ridges in case of heavily degraded images. As the filter is designed to enhance the flow pattern of ridges, so where there is ridge endings or bifurcations, it is giving the manipulated ridge orientation, which may cause spurious minutiae too.

3.4.5 Binarization and Thinning

After all the preprocessing the fingerprint image is binarized and thinned, to prepare it for minutiae point extraction. Binarization preserves the image with distinguishable ridge valley structure between 0 and 1 pixel values. The thinning algorithm reduces the pixel size of the image to one pixel wide. The resultr of binarization and thinning shows well connected ridges in the enhanced image. Figure 3.4 shows the results.



(a) Original Whorl Pattern Image (b) After Enhancement

(c) Unenhanced Thinned Image (d) Enhanced and Thinned Image

Figure 3.4: The Results of Fingerprint Image After Binarization and Thinning

3.5 Minutiae Extraction

After the preprocessing step is over, its the beginning of feature extraction phase. The most commonly employed method for minutiae point calculation is Crossing Number (CN) concept [11]. Here we take an eight-connected ridge flow pattern on the enhanced thinned image. A local window of 3×3 is put on the neighborhood of ridge pixel. The CN value is defined as half the sum of the differences between pairs of adjacent pixels in the eight-neighbourhood. Using the properties of Crossing numbe as shown in Table 3.1. The CN for a ridge pixel P is given by,

$$CN = 0.5 \sum_{i=1}^{8} |P_i - P_{i+1}| \tag{3.10}$$

Where P_i is the pixel value in the neighborhood of P.

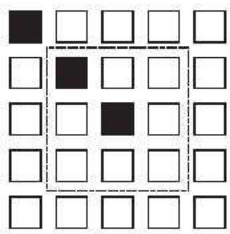
CN	Property
0	Isolated Points
1	Ridge Ending Point
2	Contunuing Ridge Point
3	Bifurcation Point
4	Crossing Point

Table 3.1: Properties of The Crossing Number

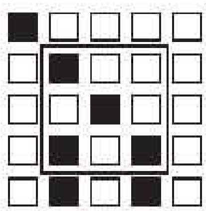
For a pixel P, its eight neighbouring pixels are scanned in an anti-clockwise direction as follows, After computing the Crossing Numbers, the pixels can be

P4	P3	P2
P5	P	P1
P6	P7	P8

classified according to the table. Like a ridge pixel with crossing number one corresponds to a ridge ending, and a CN of three corresponds to a bifurcationas shown in figure fig:cn.



(a) CN of one i.e the Ridge ending pixel



(b) CN of three i.e the bifurcation pixel

Figure 3.5: Example of Ridge Ending and Bifurcation of Pixels

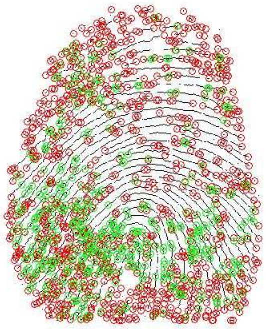
Results of Minutiae Extraction

this section represents the minutiae extraction process applied on real fingerprint images, and in the skeletonised image it can be deduced that all ridge pixels corresponding to CN of one or three, have been detected successfully. For candidate ridge ending point, firstly the eight connected ridge ending points are labeled with value 1, the next step is to count the 0 to 1 transition in the along the border of eight connected window. If the transition is 1 then it is a ridge ending. Similarly if the transition shows 3 then it is a ridge bifurcation. Figure 3.6

(a) Input Fingerprint Image

(b) Enhanced Fingerprint Image

(c) Enhanced Fingerprint Image After Thinning



(d) Input Fingerprint With Minutiae

(e) Enhanced Fingerprint Image With Minutiae

Figure 3.6: Example of Ridge Ending and Bifurcation of Pixels

The proposed algorithmis compared with Hong's[9] enhancement technique. The modified proposed algorithm shows the enhanced ridge patterns, and hence the number of minutiae detected in the fingerprinbt images are actual and the number of spurious minutiae are reduced. A comparative study of proposed algorithm with the existing Hong's enhancement scheme is tabulated in terms of minutiae findings. Table 3.2 shows a comparative study on minutiae points as ridge endings, where as an other tabulation in table 3.3 is showing the minutiae results with ridge bifurcations.

Sl. no.	Fingerprint Image	Approximate Count of Ridge Endings	
		By Hong's Method	By Proposed Method
1	012_3_1.tif	48	40
2	012_7_1.tif	52	44
3	022_3_3.tif	45	32
4	027_6_2.tif	57	39
5	027_6_5.tif	48	40
6	045_6_7.tif	93	63
7	076_5_2.tif	53	52
8	076_8_1.tif	25	21

Table 3.2: Comparative study for Ridge Endings

Sl. no.	Fingerprint Image	Approximate Count of Bifurcations	
		By Hong's Method	By Proposed Method
1	012_3_1.tif	99	86
2	012_7_1.tif	110	79
3	022_3_3.tif	130	100
4	027_6_2.tif	194	105
5	027_6_5.tif	197	128
6	045_6_7.tif	132	110
7	076_5_2.tif	141	110
8	076_8_1.tif	188	124

Table 3.3: Comparative study for Ridge Bifurcations

The graphical representation of experimental results are depicted as shown in figure 3.7, 3.8.

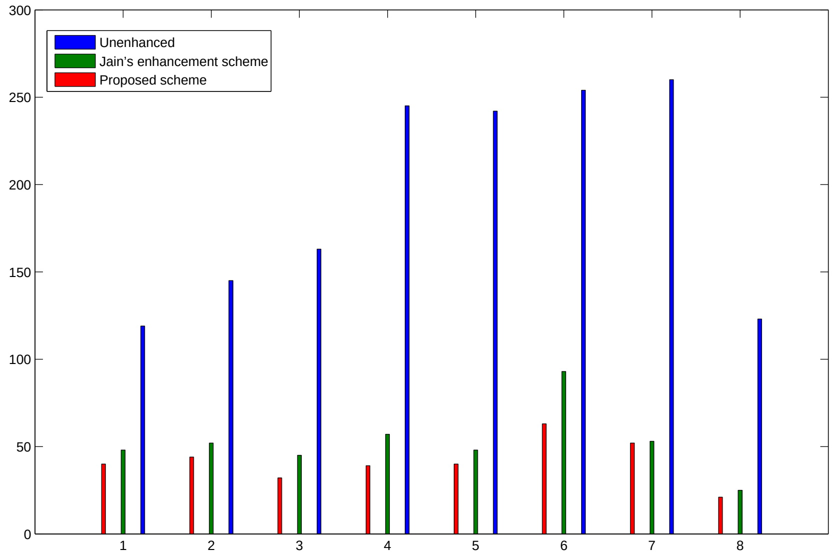


Figure 3.7: Comparative Representation of Enhancement Schemes based on ridge termination

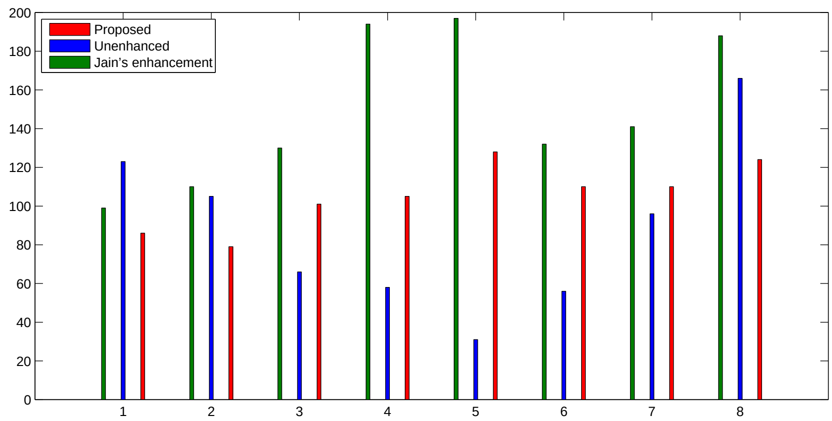


Figure 3.8: Comparative Representation of Enhancement Schemes based on ridge bifurcations

Algorithm 3.1 Contrast Enhancement

1. Generate the Histogram of the original input image.
2.To globally distingwish between ridges and valleys, make the Histogram smooth with gaussian function. $h_g(l_k) = h(l_k) * g(l_k)$ where $g(x) = e^{-x^2}$
3. Boosting the small ridges
Peak boosting from the smoothed Histogram

$$p(k) = \max_x h_g(l_k)$$

valleys boosting from the smoothed Histogram

$$h_b(l_k) = \begin{cases} (\frac{h_g(l_k)-L_{min}}{L_{max}-L_{min}})(p(k) - L_{min}) \cdot \beta + L_{min} & \text{if } h_g(l_k) > L_{min} \\ h_g(l_k) & \text{otherwise} \end{cases}$$

where $\beta = \frac{log(L_{max}-Lmin)}{logp(k)-L_{min}}$

4.To effectively suppress the quantum jump of luminance value, clipping technique is applied.
Global clipping is to clip those bins which has more than half of the peak value i.e $p(k)$ and
local clipping is to slant wise clip those values slant wise which are below half of $p(k)$.
5.Residuals from the global and local clipping are collected and redistributed to the bins uniformly.
6. Generate the contrast enhanced image with the help of luminance mapping function.
$I'_N(i, j) = m(I_N(i, j))$
where $m(l_k) = [\frac{\sum_{x=0}^{k} h_r(l_x)}{\sum_{t=0}^{L-1} h_r(l_t)}] \cdot 255$

Algorithm 3.2 Detail Enhancement

[t!]

1. An adaptive gain function is derived from luminance values of low-pass images I_n using equation,
$f_n^1(i, j) = \frac{1}{q \cdot [I_n(i,j)+1.0]^p}$ where p= the gain parameter and
q depens on p like,$q = \frac{1}{(2^p)}$
2. A noise reduction function f^2 is performed as a filter which cuts of small signals of D_n, where D_n isa noise corrupted image.
3. The deatil gain function of an image layer is given by,
$f^d(i, j) = [f^1(i, j) \cdot f^2(i, j)] * g(i, j)$

Algorithm 3.3 Resultant Enhancement

[t!]

1.The result of detail enhancement D' is obtained by accumulating the multiplication of the detail gain functions, given by, $D'(i,j) = \sum_{n=1}^{N} f_n^d(i,j) \cdot D_n(i,j)$
2.The final enhancement results out as, $I' = I'_N + D'$

Chapter 4

Conclusions and Future Work

This thesis proposes novel preprocessing approach for fingerprint images. The contribution is made to develop an efficient enhancement technique that brings out well enhanced ridge patterns. In order to overcome of the problem of over enhancement,that generate blurred images. The blurred images or only contrast enhanced images are insufficient to give good details on fingerprint ridge patterns.Hence the proposed image enhancement algorithm along with the processing steps of fingerprint image is proposed. The algorithym has successfully shown that the number of minutiae generated from the proposed DoG based approach is relatively lesser and it has given a remarkable differnce when compared with Hong based enhancement technique.

Different methods in the public domain for fingerprint image enhancement have been reviewed, and a new methodology providing better performance is proposed. In order to avoid generation of spuriour minutiae, the proposed scheme follows A novel robust HE algorithm and a modified Laplacian pyramid approach, proposed here enhances the image quality for overcoming the problem of poor enhancement. The poor enhancement leads to generation of spurious minutiae. The proposed scheme overcomes the conventional He based enhancement schemes discussed problems very well. The Experiments are being successfully implemented and evaluated with our proposed model. And a comparative result analysis is done through tables and graphs.

To conclude with this thesis, the proposed approaches have been studied and observed with a few limitations . These limitations can be refined that promotes further research in the proposed area. The performance measurement is considered only with minutiae points. Similarly core points extraction can be done and another performance measurement can be set for thealgorithm. The matching part is not included in the research work, which could have been shown the results in a better way. Theere are number of matching techniques available, yet the extrction algorithm results number of spurious and missing minutiae.

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