An Efficient DoG based Fingerprint Enhancement Scheme

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ABSTRACT
This paper 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 outperform the existing fingerprint enhancement techniques and prove the suitability of the proposed method.

Categories and Subject Descriptors
I.4.3 [**Image Processing and Computer Vision**]: Enhancement–Grayscale manipulation; I.4.3 [**Image Processing and Computer Vision**]: Enhancement–Filtering.

General Terms
Algorithms, Security, Experimentation.

Keywords
fingerprint, enhancement, Laplacian pyramid.

1. INTRODUCTION
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. The identification accuracy by matching fingerprints has been shown to be very high. The literature on the uniqueness of fingerprint minutiae leads to extracting the minutiae features reliably and using minutiae points for matching two fingerprints.

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 less spurious and more accurate minutiae points from the reliable minutiae location. In this paper contemporary fingerprint enhancement techniques are detailed along with their pitfalls and a way to assure better enhanced fingerprint image through proposed local Difference of Gaussian (DoG) based technique.

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2. RELATED WORK
Hong et al. [1] have proposed a Gabor filter based fast fingerprint enhancement algorithm and minutiae extraction from thinned skeleton of fingerprint image. Greenberg [2] have proposed two methods for fingerprint enhancement, the first method is carried out with local histogram equalization, Wiener filtering and image binarization where as the second method uses a unique anisotropic filter for direct gray scale enhancement. R. Thai [3] has introduced three additional stages to the above mentioned existing enhancement methodology of Hong et al. The stages are as follows: segmentation, (that is the primary stage of enhancement procedure), binarization, thinning. D. Maltoni et al. [4] has also proposed an algorithm that calculates a mean and standard deviation for the fingerprint image to extract the region of interest. M. Sepasian et al. [5] have proposed a Contrast Limited Adaptive Histogram Equalization (CLAHE) method for better enhancement of fingerprint images. Other enhancement approaches include band pass filters to remove undesired noise from fingerprint images [6], short time Fourier transform (STFT) approach [7], a 2-level convolution template for better time complexity on enhancement [8], a modified Gabor filter based filtering for computing ridge frequency and ridge orientation calculation [9] etc.

The fingerprint identification undergoes through several procedures including normalization, orientation estimation, image enhancement, image thresholding, image thinning, and minutiae detection and matching. Among these all procedures, image enhancement is the most computationally intensive one. Fingerprints have been in use for forensic application for many years and more recently in computer automated identification and authentication. The system highly relies on automatic extraction of minutiae from fingerprint input image and these extraction algorithms highly dependent on image processing techniques. It is observed that amongst the enhancement techniques histogram 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 due to over enhancement. Keeping the bottleneck in mind, the current research is on the scope of improvements on the histogram equalization based enhancement for fingerprint images to detect correct number of minutiae points comparing to the existing enhancement techniques. In the paper 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. Finally the reconstruction is done considering the highest decomposed layer of image and the output images of decomposed images applied with difference of Gaussian. The enhancement is followed by the binarization and thinning methods to prepare the fingerprint images for minutiae extraction phase. Minutiae are the permanent and unique feature in human fingerprint. It is used to identify any individual uniquely and hence has to be extracted properly. For the extraction process to be done with no mistake, the image has to be de-noised. In this paper, a new image enhancement technique based on histogram equalization is proposed for better result in image enhancement.

3. PROPOSED APPROACH

Fingerprint image obtained through an acquisition device is not a perfect image for direct processing to be applied on them viz. ridge feature extraction, and pattern analysis. Thus the fingerprint image after acquisition needs to go through an enhancement phase. The reliable extraction of minutiae points is relatively dependent on the fingerprint image quality and enhancement steps that can improve the clarity of the ridge structure.

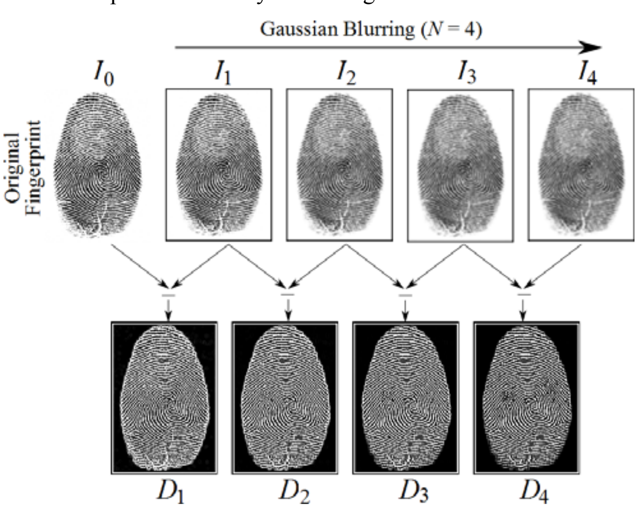

Figure 1. DoG based Laplacian pyramid generation

In the proposed research, a histogram equalization based image enhancement algorithm is proposed for fingerprint enhancement. Histogram equalization is the representative method for contrast enhancement, specifically global contrast. Pyramid based Gaussian filtering [10] is applied to obtain the Gaussian images and subsequently the differences between them as shown in Figure 1. The decomposition is based on the following equation:

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

where I_0 is the input grayscale fingerprint image, I_N is the decomposed images with Gaussian low pass filter having incremental standard deviations, N = highest decomposition layer (N=4 as taken in implementation), D_N = Laplacian images.

I_N is subjected to contrast enhancement [as in Algorithm 1] to obtain I_N' and each of D_N' are subjected to detail enhancement [as described in Algorithm 2] to obtain D'.

Enhanced fingerprint image I_0' is obtained as:

$$I_0' = I_N + D'$$

The reconstruction of the final out image which is a combination of both global and local histogram processing, aims to get the resultant image, enhanced with local information such as local contrast and fine edges in the image.

Algorithm 1. Contrast Enhancement

1. Generate the Histogram of the original input image (Figure 2).
2. To globally distinguish between ridges and valleys, make the Histogram smooth with Gaussian function as in Figure 3.
   $$h_g(l_k) = h(l_k) * g(l_k)$$
   where, $g(x) = e^{-x^2}$
3. Peak boosting from the smoothed Histogram
   $$p(K) = \max_{k \in K} h_g(l_k)$$
   Boosting histogram ridges between valleys as shown in Figure 4.
   $$h_b(l_k) = \begin{cases} \left(\dfrac{h_g(l_k) - L_{\min}}{L_{\max} - L_{\min}}\right)(p_k - L_{\min}) \cdot \beta + L_{\min} & if\ h_g(l_k) > L_{\min} \\ h_g(l_k) & otherwise \end{cases}$$
   where, $\beta = \dfrac{\log(L_{\max} - L_{\min})}{\log p_k - L_{\min}}$
4. Global clipping to clip bins having more than half of the peak value as depicted in Figure 5.
5. Local clipping is to slant wise clip those values which are below half of *p(K)* by characteristic straight line driven by two points $(0, y_1)$, (I_{max}, y_2) to obtain histogram depicted in Figure 6.
   where, $y_1 = -0.5(K).[I_{mean} / I_{mid}] + p(K)$
   and $y_2 = 0.5p(K).[I_{mean} / I_{mid}]$
6. Residuals from the global and local clipping are collected and redistributed uniformly following the equation $h_r(l_k) = h_c(l_k) + [R/(I_{\max} + 1)]$ for obtaining Figure 7.
7. Generate the contrast enhanced image with the help of luminance mapping function.
   $$I'_N(i,j) = m(I_N(i,j))$$
   where,
   $$m(l_k) = \left[\frac{\sum_{x=0}^{k} h_r(l_x)}{\sum_{t=0}^{L-1} h_r(l_t)}\right] \cdot 255$$

4. EXPERIMENTAL RESULTS

The proposed approach has been tested on publicly available free fingerprint verification database by Neurotechnology version 1.0.0.2 [11] and found to be producing very less spurious minutiae points when judged against the ground truth. Values of minutiae points are also compared against that found by applying Hong's approach. Table 1, and Table 2 depict the approximate count of ridge endings and ridge bifurcations. Likewise, Figure 8, and Figure 9 advocates the removal of spurious minutiae points

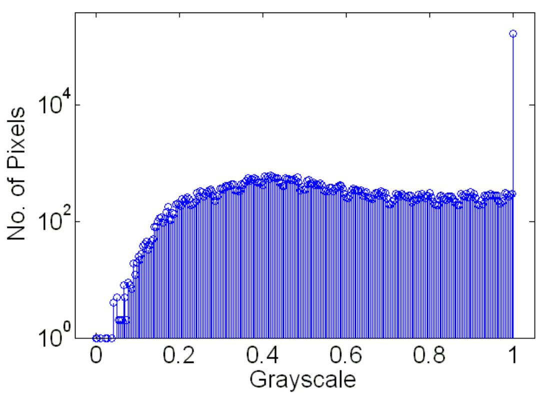

Figure 2. Histogram of original image

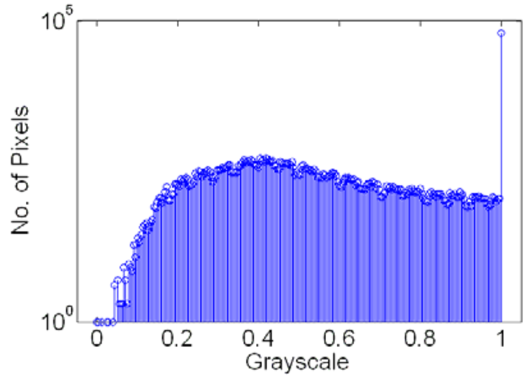

Figure 3. Smoothed histogram

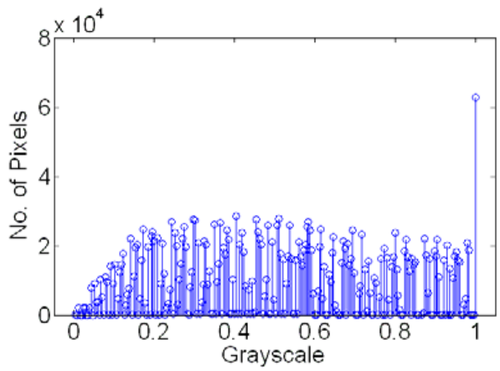

Figure 4. Histogram of boosted image

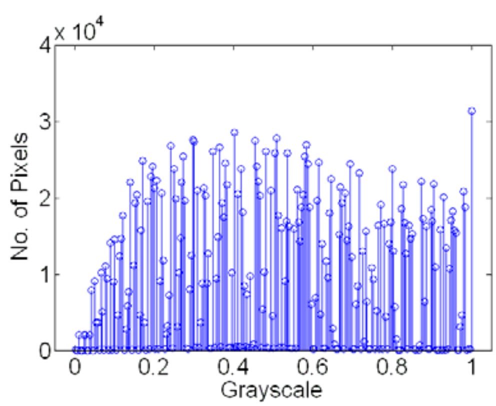

Figure 5. Histogram of global clipped image

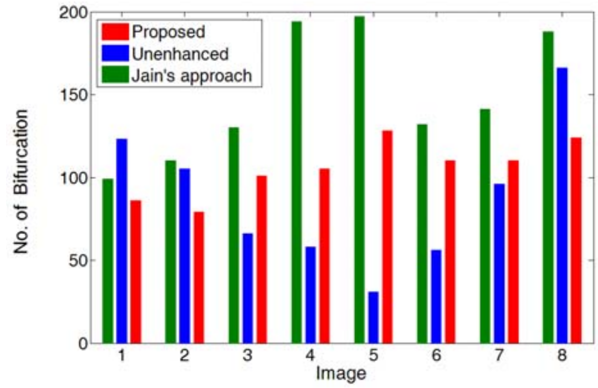

Figure 8. Comparison of no. of bifurcations from unenhanced image, Jain's enhancement, Proposed enhancement

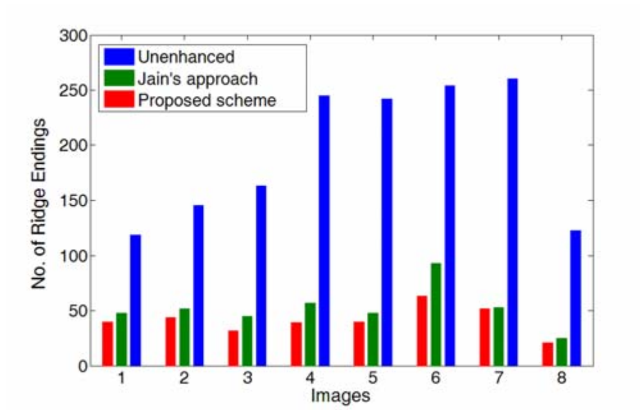

Figure 9. Comparison of no. of ridge endings from unenhanced image, Jain's enhancement, Proposed enhancement

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Algorithm 2. Detail Enhancement

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1. An adaptive gain function is derived from luminance values of low-pass images I_n using equation,

$$f_n^1(i,j) = \frac{1}{q[I_N(i,j)+1.0]^P}$$

where p is the gain parameter and q depends on p such that $q=1/2^p$.

2. A noise reduction function f_2 is performed as a filter which cuts off small signals in D_n, where D_n is a noise corrupted image.
3. The detail gain function of an image layer is given by

$$f^d(i,j) = \left[f^1(i,j)\cdot f^2(i,j)\right] * g(i,j)$$

4. The result of detail enhancement D' is obtained by accumulating the multiplication of the detail gain functions, given by

$$D'(i,j) = \sum_{n=1}^{N} f_d^n(i,j)\cdot D_n(i,j)$$

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by application of the proposed fingerprint enhancement method. The final enhancement result is evaluated through the equation $I' = I_N' + D'$ using Algorithm 1 and Algorithm 2.

5. CONCLUSIONS

The proposed fingerprint enhancement method works robustly even on low quality fingerprints and outputs contrast enhanced fingerprints from which genuine minutiae points can be extracted. The enhancement process reduces the detection of no. of spurious minutia points. Hence the later stages of fingerprint recognition can perform with higher accuracy.

6. ACKNOWLEDGMENTS

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