© 2016 IJSRSET | Volume 2 | Issue 4 | Print ISSN : 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Fingerprint Image Enhancement using DWT Domain with Adaptive Gamma Parameter

K. Divya[1], K. Thangavel[2], K. Sasirekha[3]
Department of Computer Science, Periyar University, Salem, Tamil Nadu, India

ABSTRACT

The efficiency of a fingerprint authentication system depends on the quality of the fingerprint image. Enhancement of the fingerprint image is indispensable to get a good quality image. In this paper, a novel method is proposed to enhance the fingerprint image using Adaptive Gamma Parameter with Discrete Wavelet Transform (DWT). An automatic transformation technique that improves the brightness of low quality images via the gamma correction and probability distribution of luminance pixels using DWT is presented. In this study, experiments have been conducted on the fingerprint database FVC2004. The Peak Signal-to-Noise Ratio (PSNR), Signal-to-Noise Ratio (SNR), Root Mean Square Error (RMSE) and Mean Square Error (MSE) measures have been used to compare the proposed method with the existing methods.

Keywords: Fingerprint; Gamma Correction; DWT; Histogram Equalization

I. INTRODUCTION

Biometric authentication refers to verify individuals based on their physiological and behavioral characteristics. Nowadays biometric technologies are widely used in many applications for various purposes of personal authentication. Biometric methods provide a higher level of security and are more convenient for the user than the traditional methods of personal authentication such as passwords and tokens [1][2]. Among all the biometrics, fingerprint is a great source for identification of individuals. Fingerprints have been used in Forensic Science for a long time for personal identification. This is because the fingerprints of an individual are unique and do not change throughout one's life. This makes them an ideal signature of a person [3], [4], [5].

Image enhancement plays a vital role in image processing applications where people (the expert) make decisions with respect to the image information. Form of image enhancement include noise reduction, edge enhancement and contrast enhancement. Enhancement may be the technique of improving the superiority of a electrically stored image. To produce a picture lighter or darker or to increase or decrease contrast. Image enhancement is to improve the sensitivity of information in images for human viewers, or to offer enhanced input for other regular image processing techniques. In this procedure, more than one attributes of the image are customized.

The possibility of attributes and the direction they are customized are specific to certain task. Contrast enhancement plays an important role in the improvement of visual quality for computer vision, pattern recognition, and the processing of digital images. Poor contrast in digital video or images can result from many circumstances, including lack of operator expertise and inadequacy of the image capture device. Unfavorable environmental conditions in the captured scene, such as the presence of clouds, lack of sunlight or indoor lighting, and other conditions, might also lead to reduced contrast quality [2].

Conventional techniques for contrast enhancement include gray-level transformation based techniques and histogram based processing techniques (viz., Histogram Equalization (HE), Adaptive Histogram Equalization (AHE), etc.). Other advanced histogram based enhancement methods include Bi-Histogram Equalization (BHE), Block-Overlapped Histogram Equalization, and Multi-Scale Adaptive Histogram

Equalization. Gamma Correction techniques make up a family of general Histogram Modification techniques obtained simply by using a varying adaptive parameter γ. The simple form of the Transform-based Gamma Correction (TGC) is derived by

$$T(l) = l_{max}(l/l_{max})^{\gamma} \quad (1)$$

where lmax is the maximum intensity of the input. The intensity l of each pixel in the input image is transformed as T (l) after performing Eq.(1). The gamma curves illustrated with γ >1 have exactly the opposite effect as those generated with γ < 1. It is important to note that gamma correction reduces toward the identity curve when γ = 1. The contrast is directly modified by gamma correction, different images will exhibit the same changes in intensity as a result the fixed parameter.

Fortunately, the probability density of each intensity level in a digital image can be calculated to solve this problem. The probability density function (pdf) can be approximated by

$$pdf(l) = n_l/(N) \quad (2)$$

where nl is the number of pixels that have intensity l and N is the total number of pixels in the image. The cumulative distribution function (cdf) is based on pdf , and is formulated as

$$cdf(l) = \sum_{k=0}^{l} pdf(k) \quad (3)$$

After the cdf of the digital image is obtained from Eq. (3) Traditional Histogram Equalization (THE) directly uses cdf as a transformation curve expressed by

$$T(l) = cdf(l) l_{max.} \quad (4)$$

Various disadvantages exist in regard to the TGC and THE methods such as over- enhancement, under – enhancement, some low intensity levels are still decreased, moderate intensity levels are significantly increased, and high intensity levels are significantly decreased.

The wavelets have advantages over traditional spatial and Fourier methods in analyzing physical situations where the image contains discontinuities. With Wavelet Transform gaining popularity in the last two decades various algorithms for enhancement in wavelet domain were introduced.

In order to overcome the aforementioned problems, a hybrid HM method is developed by combining the TGC and THE methods in wavelet domain which is computationally inexpensive yet effective method. The proposed method uses DWT for image decomposition and Inverse Discrete Wavelet Transform (IDWT) for image reconstruction.

The paper is organized as follows. Section 2 presents the review of existing methods for image enhancement. In section 3, a method for Fingerprint Image Enhancement in Wavelet Domain has been proposed. Section 4 provides experimental results of the proposed method on fingerprint images and compared with the results of the existing methods. Finally this paper concludes with some perspectives in section 5.

II. METHODS AND MATERIAL

2. Existing Methods For Image Enhancement

2.1. Histogram Equalization

Basically Histogram is a graphic representation of the distribution of data. Histogram equalization is a technique for adjusting image intensities to enhance contrast. The histogram shows how certain times a specific gray level (intensity) appears in an image. Histogram equalization is a technique for enhancing the contrast and contrast adjustment in image processing. This technique is utilized in various applications areas such as example for medical image processing, object tracking, speech recognition, give the better views of bone structure in x-ray images, and to enhanced detail in photographs backgrounds and foregrounds which can be both bright or both dark.

Histogram Equalization often produces unrealistic effects in photographs; however it is very useful for scientific images like thermal, satellite or x-ray images, often the same class of images to which one would apply false-color. Histogram Equalization can also produce undesirable effects (like visible image gradient) when applied to images with low color depth. For example, if applied to 8-bit image displayed with 8-bit gray-scale palette it will further reduce color depth (number of unique shades of gray) of the image. Histogram Equalization will work the best when applied to images with much higher color depth than palette size, like continuous data or 16-bit gray-scale images.

There are two ways to think about and implement histogram equalization, either as image change or as palette change. The operation can be expressed as P (M (I)) where I is the original image, M is histogram equalization mapping operation and P is a palette. If we define a new palette as P' = P(M) and leave the image I unchanged then histogram equalization is implemented as palette change.

On the other hand if palette P remains unchanged and image is modified to I' = M (I) then the implementation is by image change. In most cases palette change is better as it preserves the original data.

Modifications of this method use multiple histograms, called sub-histograms, to emphasize local contrast, rather than overall contrast. Examples of such methods include Adaptive Histogram Equalization, Contrast Limiting Adaptive Histogram Equalization or CLAHE, Multi-Peak Histogram Equalization (MPHE), and Multipurpose Beta Optimized Bi-Histogram Equalization (MBOBHE).

The goal of these methods, especially MBOBHE, is to improve the contrast without producing brightness mean-shift and detail loss artifacts by modifying the HE algorithm[7]. The Cumulative Distribution Function corresponding to px is defined as

$$\mathrm{cdf}_x(i) = \sum_{j=0}^{i} p_x(j) \tag{5}$$

which is also the image's accumulated normalized histogram.

Histogram specification is of interest in many other image processing tasks. For example, most thersholding segmentation algorithms are based on mixtures of Gaussian probability density functions and optimal schemes are expected to be obtained if such conditions are met. Similarly, optimal coding could be obtained if exact histogram specification were available [7]. The image histogram is specified according to a certain model of the HVS such that the subjectively perceived image has an equalized histogram.

2.2. Adaptive Histogram Equalization

Adaptive Histogram Equalization (AHE) is a computer image processing technique used to improve contrast in images. It differs from ordinary histogram equalization in the respect that the adaptive method computes several histograms, each corresponding to a distinct section of the image, and uses them to redistribute the lightness values of the image. It is therefore suitable for improving the local contrast and enhancing the definitions of edges in each region of an image.

It's used to enhance contrast in images. Histogram equalization emphasize only on local contrast place of overall contrast. Adaptive histogram equalization overcomes from this issue, this technique applicable for overall techniques. Once the image contains regions that are extensively lighter and darker, the contrast in those regions will not be adequately enhanced. So Adaptive Histogram Equalization computed properly image regions. AHE has a tendency to over amplify noise in relatively homogeneous regions of an image. A variant of adaptive histogram equalization called Contrast Limited Adaptive Histogram Equalization (CLAHE) prevents this by limiting the amplification.

Adaptive Histogram Equalization (AHE) improves on this by transforming each pixel with a transformation function derived from a neighborhood region.

The derivation of the transformation functions from the histograms is exactly the same as for ordinary histogram equalization: The transformation function is proportional to the Cumulative Distribution Function (CDF) of pixel values in the neighborhood.

The size of the neighborhood region is a parameter of the method. It constitutes a characteristic length scale: contrast at smaller scales is enhanced, while contrast at larger scales is reduced. Due to the nature of histogram equalization, the result value of a pixel under AHE is proportional to its rank among the pixels in its neighborhood.

This allows an efficient implementation on specialist hardware that can compare the center pixel with all other pixels in the neighborhood [8]. An un-normalized result value can be computed by adding 2 for each pixel with a smaller value than the center pixel, and adding 1 for each pixel with equal value. When the image region containing a pixel's neighborhood is fairly homogeneous, its histogram will be strongly peaked, and the transformation function will map a narrow range of pixel values to the whole range of the result image. This causes AHE to over amplify small amounts of noise in largely homogeneous regions of the image [10].

2.3. Adaptive Gamma Correction With Weighting Distribution

The adaptive gamma correction (AGC) is formulated as follows

$$T(l) = l_{max}\,(l|l_{max})^{\gamma} = l_{max}\,(l|l_{max})^{1-cdf(l)} \qquad (6)$$

Gamma encoding of images is used to optimize the usage of bits when encoding an image, or bandwidth used to transport an image, by taking advantage of the non-linear manner in which humans perceive light and color [6]. If images are not gamma-encoded, they allocate too many bits or too much bandwidth to highlights that humans cannot differentiate, and too few bits/bandwidth to shadow values that humans are sensitive to and would require more bits/bandwidth to maintain the same visual quality. Gamma encoding of floating-point images is not required (and may be counterproductive), because the floating-point format already provides a piecewise linear approximation of a logarithmic curve.

Although gamma encoding was developed originally to compensate for the input–output characteristic of cathode ray tube (CRT) displays, that is not its main purpose or advantage in modern systems. In CRT displays, the light intensity varies nonlinearly with the electron-gun voltage. Altering the input signal by gamma compression can cancel this nonlinearity, such that the output picture has the intended luminance. However, the gamma characteristics of the display device do not play a factor in the gamma encoding of images and video – they need gamma encoding to maximize the visual quality of the signal, regardless of the gamma characteristics of the display device [6]. The similarity of CRT physics to the inverse of gamma encoding needed for video transmission was a combination of luck and engineering, which simplified the electronics in early television sets.

3. Proposed Method for Fingerprint Image Enhancement Using Wavelets

Wavelets are mathematical functions that analyze the data according to scale or resolution. Wavelet transforms have become one of the most important and powerful tool for image processing [11]. Wavelet decomposition produces four sub-bands as shown in fig.1.

LL (Approximation)	HL (Horizontal)
LH (Vertical)	HH (Diagonal)

Figure 1: Wavelet Decomposition using DWT

Here, H and L denote high and low-pass filters respectively. The LL subband is the low resolution residual consisting of low frequency components and this subband which is further split at higher levels of decomposition.

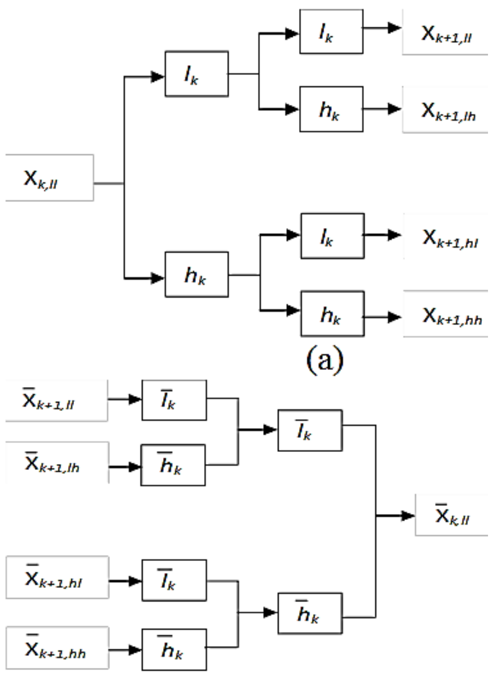


Figure 2: one level filter bank implementation of DWT. (a)Forward Pass (b) Backward Pass

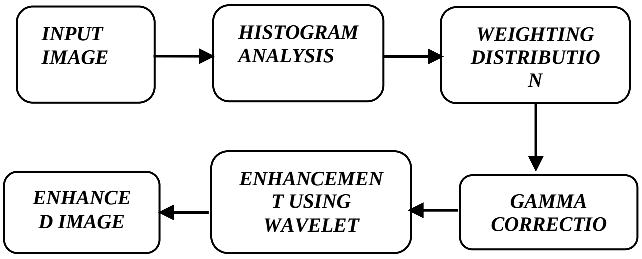


Figure 3: One level filter bank implementation of DWT

The block diagram of the proposed method is shown in fig. 3. The Weighting Distribution (WD) function is applied to slightly modify the statistical histogram and lessen the generation of adverse effects.

Furthermore, the weighting distribution function is also applied to slightly modify the statistical histogram and lessen the generation of adverse effects [13]. The WD function is formulated as:

$$\mathrm{pdf_w}(l) = \mathrm{pdf_{max}}\left(\frac{\mathrm{pdf}(l)-\mathrm{pdf_{min}}}{\mathrm{pdf_{max}}-\mathrm{pdf_{min}}}\right)^{\alpha} \quad (7)$$

where α is the adjusted parameter, pdf max is the maximum pdf of the statistical histogram, and pdf min is the minimum pdf. Based on Equation (6), the modified cdf is approximated as

$$\mathrm{cdf_w}(l) = \frac{\sum_{l=0}^{l_{max}} \mathrm{pdf_w}(l)}{\sum \mathrm{pdf_w}} \quad (8)$$

where the sum of pdfw is calculated as follows:

$$\sum \mathrm{pdf_w} = \sum_{l=0}^{l_{max}} \mathrm{pdf_w}\,(l) \quad (9)$$

Finally, the gamma parameter based on cdf of Equation (6) is modified as follows:

$$\gamma = 1 - \mathrm{cdf_w}(l) \quad (10)$$

The fingerprint image is decomposed using DWT into four sub-bands. The illumination information is embedded in LL sub-band. The edges are concentrated in other sub-bands (i.e. LH, HL, and HH). Hence, separating the high frequency sub-bands and applying the illumination enhancement in LL subband only, will protect the edge information from possible degradation.

The computed gamma parameter is applied to low frequency subband. Finally the enhanced image is computed by applying inverse DWT.

III. RESULTS AND DISCUSSION

Experimental Results

The performance of the proposed method is compared with Histogram Equalization, Adaptive Histogram Equalization and Adaptive Gamma Parameter. The proposed method has been implemented using MATLAB.

4.1 Dataset

The proposed method is tested on Database FVC2004 from Fingerprint Verification Competition (FVC) [15]. The images are resized to 256 x 256 for implementation and further analysis.

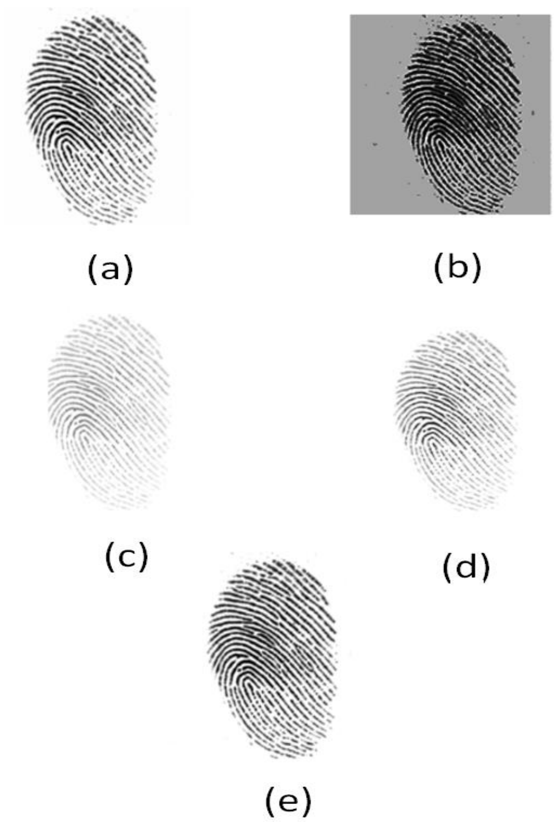


Figure 4: Fingerprint image Enhancement: (a)Original Image (b)Histogram Equalization (c)Adaptive Histogram Equalization (d)Adaptive Gamma Parameter (e) Proposed method in Wavelet domain

4.2 Quantitative Measure

The image quality metrics such as Mean Square Error (MSE), Root Mean Square Error (RMSE), and Signal to Noise Ratio (SNR) and Peak Signal to Noise Ratio (PSNR) are used to evaluate the performance. The metrics are shown in Table 1.

Table 1. Quantitative Metrics

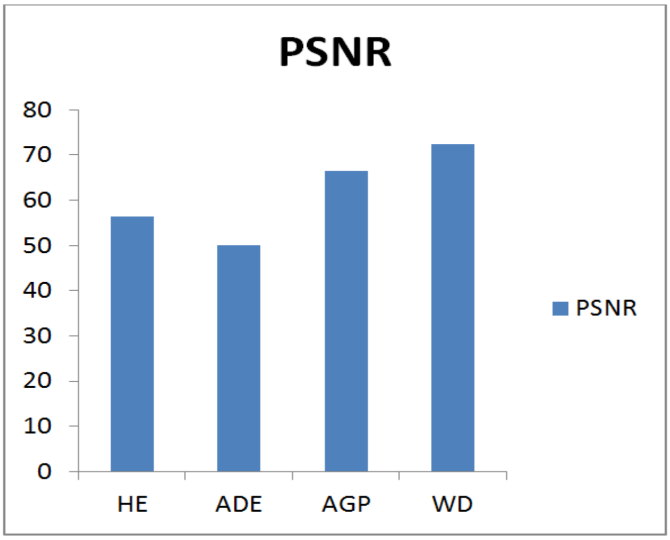
Metric	Formula
MSE	$\frac{\sum_{m,n}[I_1(m,n)-I_2(m,n)]^2}{m*n}$
RMSE	$\sqrt{\frac{\sum_{m,n}[I_1(m,n)-I_2(m,n)]^2}{m*n}}$
SNR	$10\log_{10}\left(\frac{Var(I_1)}{Var(I_2)}\right)$
PSNR	$10\log_{10}\left(\frac{R^2}{MSE}\right)$

Where I1 is the input image, I2 is the enhanced image, m and n are the number of rows and columns in the image respectively and R is the maximum fluctuation in the input image data type. In this experiment, R is set as 255, since the image data type is 8-bit unsigned integer.

The following tables show the mean value of MSE, RMSE, PSNR and SNR of FVC2004 fingerprint database.

Table 2. Performance Evaluation for Fingerprint Enhancement

METHOD	MSE	RMSE	PSNR	SNR
Histogram Equalization	0.158403	0.390912	56.50731	-3.15952
Adaptive Histogram Equalization	0.647113	0.803702	50.07111	-15.957
Adaptive gamma parameter	0.015404	0.122775	66.48554	10.28951
Proposed method in wavelet domain	**0.005215**	**0.067096**	**72.32957**	**-2.40932**



Enhancement Methods

Figure 5. Comparison of PSNR for different Enhancement methods

HE-Histogram Equalization, AHE-Adaptive Histogram Equalization, AGP-Adaptive Gamma Parameter, WD-Wavelet Domain.

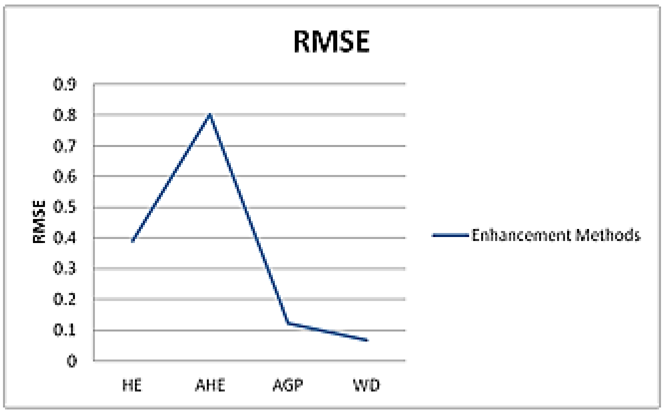


Figure 6 : Comparison of RMSE for different Enhancement methods

It is observed that from the quantitative measures shown in figure 5 and figure 6 that the proposed method using wavelet gives better result in terms of PSNR, SNR, MSE and RMSE when compared to Histogram Equalization, Adaptive Histogram Equalization and Adaptive Gamma Parameter.

IV. CONCLUSION

In this paper, a novel method to enhance the fingerprint image using adaptive gamma parameter and Discrete Wavelet Transform (DWT) were proposed. Initially the gamma parameter was computed using weighted distribution and it then was applied to LL subband of decomposed image. Then the enhanced image was obtained using inverse wavelet transform. The quantitative measures showed that the proposed method in wavelet domain produced better results in terms of PSNR, SNR, MSE and RMSE.

V. ACKNOWLEDGMENT

The second author immensely acknowledges the UGC, New Delhi for partial financial assistance under UGC-SAP (DRS) Grant No. F.3-50/2011.

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