HYBRID FINGERPRINT IMAGE COMPRESSION TECHNIQUE USING WAVELET TRANSFORMATION AND BLOCK TRUNCATION CODING WITH RLE

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ABSTRACT

The Hybrid technique that combines the Wavelet Transformation and Block Truncation Coding is a new framework proposed for fingerprint image compression. The proposed technique includes image enhancement system, forward DWT, encoding system, decoding system and inverse DWT. Image enhancement techniques like histogram equalization and wiener filtering has been performed on the image before Wavelet transformation so that the noisy image can also be retrieved fast. Wavelet based compression are largely used due to the competitive compression ratios that can be achieved at high quality without much blocking artefacts. The BTC converts a gray level image into a binary image with a predefined threshold. The coded bits are written into separate text file as sequence of symbol pairs (run, value) using run-length coding. Experiments on an image database of grayscale JPEG (uncompressed) images shows that the proposed technique performs well in compression and decompression. The Quality metrics used are CR, SNR, MSE and PSNR.

General terms
AFIS, FBI, MSE, PSNR, CR, SNR

Keywords: histogram equalization, wiener filtering, forward DWT, inverse DWT, block truncation coding, RLE.

1. INTRODUCTION

An image may be defined as a rectangular array of pixels. The pixels of a grayscale image are a non-negative integer interpreted as the intensity (brightness, luminosity) of the image. When image pixel intensities are in the range [0, 2N-1], then we say that the image is of N bit depth, or that it is an N-bit image. Typical grayscale images are of bit depths from 8 to 16 bits.

2. OBJECTIVE

Image compression is the application of data compression on digital images. In effect, the objective is to reduce redundancy of the image data in order to be able to store or transmit data in an efficient form.

Large volume of fingerprints are collected and stored everyday for a wide range of applications, including Individual Identification, Forensics, Access control etc., and are evident from the database of FBI which contains more than 200 million fingerprints. An AFIS requires that the input fingerprint must be matched with candidates with in a larger number of fingerprints. Since large volume of data in a database consumes more amount of memory, the information contained in fingerprints must therefore be compressed.

Fingerprint images exhibit characteristic high energy in certain high frequency bands resulting from the ridge valley pattern and other structures. These ridge structures (termination and bifurcation) called minutiae details of the fingerprint images and they are not always well defined therefore, an enhancement is required before compression [1]. In this work the enhancement is carried out using local histogram equalization and Wiener Filtering.

The proposed method mainly focuses on an Adaptive fingerprint compression on enhanced fingerprint images using discrete wavelet transformation and block truncation coding to get better image compression ratio without compromising the image quality.

3. PROPOSED METHODS FOR FINGERPRINT IMAGE COMPRESSION

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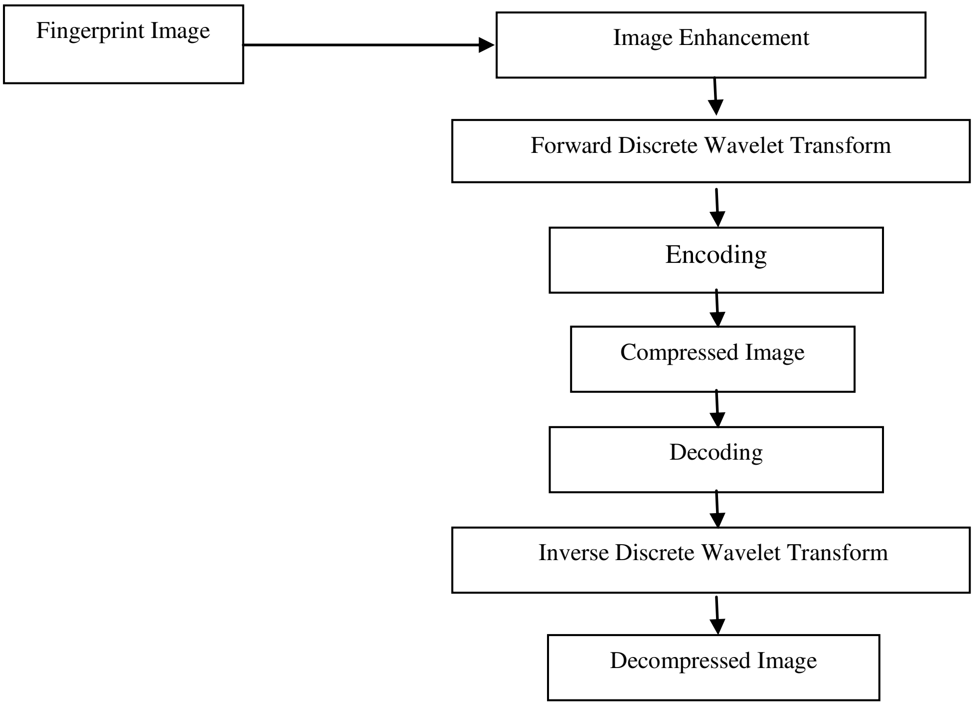

Figure-1. Developed system.

- Image Enhancement processes consist of a collection of techniques that seek to improve the visual appearance of an image or to convert the image to a form better suited for analysis by a human or machine [2]. Enhancement of an image can be implemented by using different operations of brightness increment, sharpening, blurring or noise removal.
- Like any transform-based compression algorithm, wavelet compression works in 3 stages: Transform, Quantization, and Entropy coding [21].
- In transform step, the Wavelet compression is different from other transform based compression like DCT where the transform matrix is fixed. The DWT is a widely used multi-resolution analysis tool due to its capability of space- frequency decomposition of images [9], energy compaction of low frequency sub-bands, space localization of high frequency sub-bands, flexibility in time frequency timing, attractive properties for extracting features from nonstationary signals, ability to match human vision spectral properties, possibility of using short filters and the absence of blocking artefacts. Wavelet packets facilitate a flexible representation by allowing decompositions at every node of the tree resulting in an explicit structure for specific applications.
- Quantization, which generally means the mapping of a broad range of input values to a limited number of output values [22]. The HICT opted BTC for the quantization of DWT coefficients, which is a technique that process data in the spatial domain itself and it is based on preserving the first and second statistical moments of the image [Delp and Mitchell,1979]. Similarly for entropy coding, a lossless bit packing technique Run-Length Encoding is used.
- To produce the reconstructed image, the decoded wavelet coefficients are run through an Inverse DWT.
- The output was compared based on a set of quality measures like Compression ratio (CR), Signal-to-Noise Ratio (SNR), Peak-Signal-to-Noise-Ratio (PSNR) and Mean Square Error (MSE).

4. IMAGE ENHANCEMENT

Image noise is the random variation of brightness or color information in images produced by the sensor and circuitry of a scanner or digital camera. Image noise is generally regarded as an undesirable by-product of image capture.

The noise on the fingerprint images (see Figure-2) can be related to dryness or high humidity of the skin, excessive or limited pressure of the fingertip on the sensor and bad condition of the skin surface (e.g. illness, scratches, usage of abrasive material and other particular working conditions) The failure to acquire or enroll ratio is considered to be few percent, depending on operational conditions and on the population. Finger scanning is not immune to environmental disturbance. As the image is captured when the finger is touching the scanner device it is possible that dirt, condition of the finger all affect the quality of the fingerprint. Furthermore, such methods may be subject to attacks by hacker when biometric feature are transferred via Internet.

Image enhancement techniques are designed to improve the quality of an image as perceived by a human being. An enhancement algorithm is one that yields a better-quality image for the purpose of some particular application which can be done by either suppressing the

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noise or increasing the image contrast. Image enhancement algorithms are employed to emphasis, sharpen or smoothen image features for display and analysis. Enhancement methods are application specific and are often developed empirically.

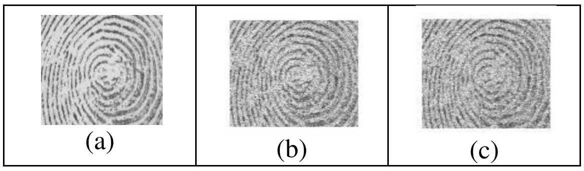

Figure-2. Sample images, a) Original image, b) Noise image 1, & c) Noise image 2.

4.1 Histogram

Histogram is one of the important features which are very related to image enhancement. The histogram does not only gives us a general overview on some useful image statistics (e.g. mode, and dynamic range of an image), but it also can be used to predict the appearance and intensity characteristic of an image. If the histogram is concentrated on the low side of the intensity scale, the image is mostly a dark image. On the other hand, if the histogram is concentrated on the high side of the scale, the image is mostly a bright image. If the histogram has a narrow dynamic range, the image usually is an image with a poor contrast [4] (see Figure-3).

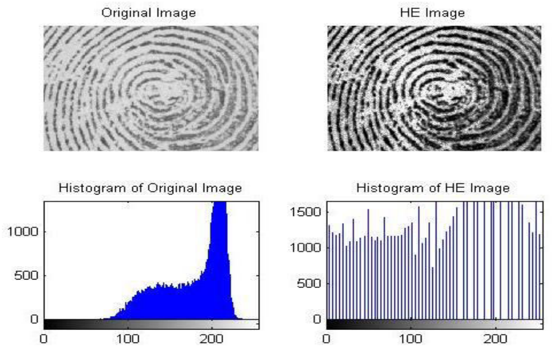

Figure-3. Original image and its histogram and the histogram equalized image and its histogram.

4.2 Wiener filter

Filters are the basic elements in the signal processing system. Filter is a device used to suppress the unwanted signal i.e. noise from the desired signal and there are several techniques are used for filtering.

Wiener filter is formulated to map an input signal to the output that is as close to the desired signal as possible. A signal is completely recoverable from noise when the spectra of the signal and noise don't overlap each other. If the signal and noise occupies different parts of the frequency spectrum, they can be separated by using either low pass or high pass filter. If the signal and noise has overlap spectra, in this case it is not possible to completely separate the signal from noise but the effects of noise can be reduced by using wiener filter. The choice of wiener filter order affects:

- The ability of the filter to remove the distortion and reduce the noise,
- The computational complexity of the filter, and
- The numerical stability of the wiener solution

And also the wiener filter has a limited practical usefulness because of the following reasons;

- It requires the auto correlation matrix R and the cross correlation vector P both of which are not known.
- It involves matrix inversion, which is time consuming.
- If the signals are non-stationary then both R and P will change with time and so will have to be computed repeatedly.

The following Figure-4 shows that the Wiener filter is effective in minimizing degradation and to a certain extent, it minimizes the random noise.

Figure-4. Result of Wiener filter on enhanced image.

5. DISCRETE WAVELET TRANSFORMATION

What is a Wavelet Transform? Wavelets are functions defined over a finite interval and having an average value of zero. The basic idea of the wavelet transform is to represent any arbitrary function (t) as a superposition of a set of such wavelets or basis functions. These basis functions or baby wavelets are obtained from a single prototype wavelet called the mother wavelet, by dilations or contractions (scaling) and translations (shifts). The Discrete Wavelet Transform of a finite length signal x(n) having N components, for example, is expressed by an N x N matrix. For a simple and excellent introduction to wavelets, see [5].

Why Wavelet-based Compression? Despite all the advantages of JPEG compression schemes based on DCT namely simplicity, satisfactory performance, and availability of special purpose hardware for implementation; these are not without their shortcomings. Since the input image needs to be ``blocked," correlation across the block boundaries is not eliminated. This results in noticeable and annoying ``blocking artifacts" particularly at low bit rates as shown in Figure-5.

(a) (b)

Figure-5. (a) Original lena image, and (b) Reconstructed lena with DC component only, to show blocking artefacts.

Lapped Orthogonal Transforms (LOT) [6] attempt to solve this problem by using smoothly overlapping blocks. Although blocking effects are reduced in LOT compressed images, increased computational complexity of such algorithms do not justify wide replacement of DCT by LOT.

Over the past several years, the wavelet transform has gained widespread acceptance in signal processing in general and in image compression research in particular. In many applications wavelet-based schemes (also referred as sub band coding) outperform other coding schemes like the one based on DCT. Since there is no need to block the input image and its basis functions have variable length, wavelet coding schemes at higher compression avoid blocking artefacts. Wavelet-based coding [7] is more robust under transmission and decoding errors, and also facilitates progressive transmission of images. In addition, they are better matched to the HVS characteristics. Because of their inherent multi-resolution nature [8], wavelet coding schemes are especially suitable for applications where scalability and tolerable degradation are important. Two-Dimensional DWT is calculated using a series of a one dimensional DWTs.

The input image is a fingerprint image of 320 x 240 in JPEG (uncompressed) format. The Discrete Wavelet Transform has to be applied on it. DWT splits the image into four sub-bands - LL, LH, HL, HH. This splitting can be done repeatedly upto n times but as the level increases the compression though increases but the information loss also increases above tolerable levels. Wavelet Transform at level 2 is manageable but at level 1 is quite good.

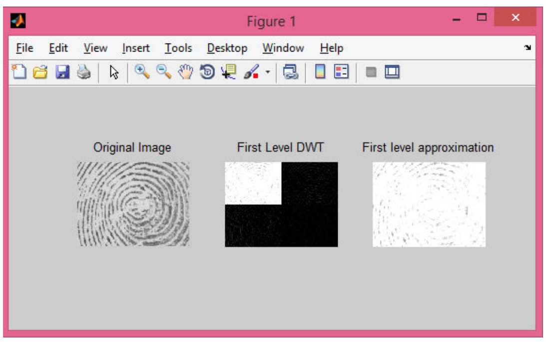

Figure-6. First level DWT and level-one approximation (A1).

A single-level decomposition of the Fingerprint image using the 'bior4.4' wavelet is shown in the Figure-6. This generates the coefficient matrices of the level-one approximation (A1) and horizontal, vertical and diagonal details (H1, V1, D1 respectively). A two level decomposed Fingerprint image is obtained after performing discrete wavelet transform on the single level decomposed fingerprint image. The coefficient matrices of the level-two approximation (A2) and horizontal, vertical and diagonal details (H2, V2 & D2) respectively are obtained. The coefficients of all the components of second-level decomposition (that is, the second-level approximation and the first two levels of detail) are returned.

6. ENCODING AND DECODING

The source images with their 8-bit gray-scale resolution are continuous-tone images as far as the compression standard is concerned, and the resulting wavelet coefficients are regarded as analog input by the encoding process.

The basic idea of Block Truncation coding method is to split the image into a number of small non-overlapping square blocks and then the gray levels within each block are approximated by one of two gray levels l1 and l2. These gray levels l1 and l2 are so chosen that mean and variance of original and approximated gray levels of each block be the same [10].

Suppose an image of size N X N is divided into n numbers of blocks each of size mxm. Assume that gray levels within i^{th} block is approximated as,

$$\sim g_i(r,c) = \begin{cases} l1, & if\ gi(r,c) < thres \\ l2, & otherwise \end{cases}$$

For all (r,c), where *thres* is a predefined threshold for converting a gray level image into a binary image and it is selected based on the largest difference in graylevel.Since a binary image of size m x m needs M bits to be represented, then the amount of data reduction is given by,

$$C = \frac{Mb - M - 2b}{Mb}\ X\ 100\%$$

The decoding process regenerates the gray level pattern with the stored parameters or by using a look-up table, respectively.

6.1 Run length encoding

RLE (Run Length Encoding) has to be applied to the resulting bit stream after encoding is applied to the DWT. It will help to reduce the size of the bit stream already generated. At the receiving end, the original bit stream can be easily recovered by applying inverse RLE.

6.2 Quality measures

Let *x* (*m*, *n*) denotes the samples of original image, and *x'* (*m*, *n*) denotes the samples of compressed

image. M and N are number of pixels in row and column directions respectively [9].
Mean Square Error is given by:

$$MSE = (x(m, n) - x'(m, n))^2 / MN$$

Peak Signal-to-Noise Ratio is given as:

$$PSNR = 10\log_{10} (2^B - 1)^2/MSE,$$

where B is the Block size

Decoding is the reverse process of the encoding and it results the original image.

7. RESULTS AND DISCUSSIONS

The above discussed algorithm has been implemented in MATLAB 7.0. In this image compression algorithm, sample fingerprint images shown in Figure-7 of size 320 x 240 were utilized to test the adopted methods in the algorithm. To compare between the used compressions methods, 4 parameters were calculated. These are Compression Ratio (CR), Peak-Signal-Noise-Ratio (PSNR), Mean Square Error (MSE), and Signal-to-Noise-Ratio (SNR). Table-1 represents the results for MSE and PSNR for the sample fingerprint image by using different enhancement methods and this result was also plotted in Figure-8.

Table-1. MSE and PSNR values for the proposed enhancement techniques.

HE& Filters	MSE	PSNR
LHE & Median filter	24.9161	34.166
LHE & wiener filter	12.152	56.3133
LHE & Inverse filter	52.3991	30.9376

The transformation techniques performed on a gray scale fingerprint images after enhancement (LHE and Median Filtering) are: (i) FFT (Fast Fourier Transformation), (ii) DCT (Discrete Cosine Transformation), and (iii) DWT (Discrete Wavelet Transformation). The reasons for adopting wavelet compression technique is largely due to the fact that competitive compression ratios could be achieved at high quality without bothering blocking artefacts of the JPEG-style discrete-cosine-transform (DCT) compression. Because of these advantages, the DWT was adopted, for the transformation step in the proposed hybrid fingerprint image compression technique and further BTC (Block Truncation Coding) and RLE (Run Length Encoding) were used for quantization and entropy encoding.

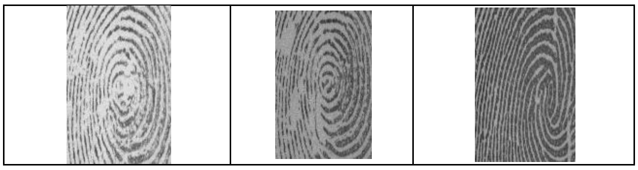

Figure-7. Sample images of size 320 X 240.

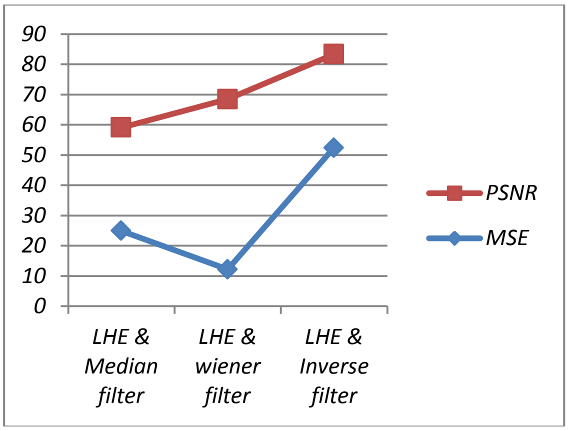

Figure-8. MSE and PSNR values of the sample Fingerprint image for the proposed enhancement techniques.

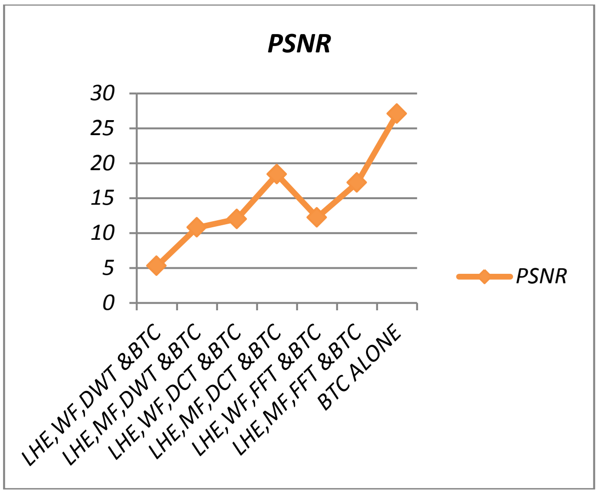

Figure-9. PSNR comparison for the proposed transformation methods.

Table-2 represents the results for Compression Ratio (CR), MSE, SNR, and PSNR for the sample fingerprint images by using different transformation technique by adopting encoding (BTC and RLE) and decoding techniques. This result was also plotted in Figures 9, 10, and 11. And some of the sample fingerprint images were shown in Figure-12 after decompression. A 20 dB or higher PSNR indicates that the image is of good quality and it can be seen that, the proposed hybrid compression technique with WF, DWT, BTC and RLE gives good MSE, PSNR and CR value compare to the other methods and the reconstructed image is also good for further use.

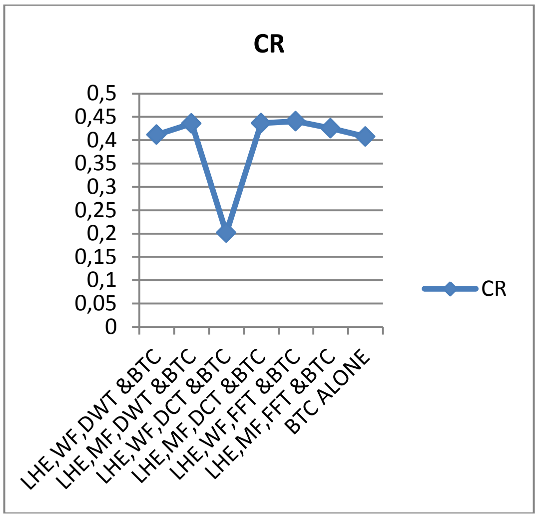

Figure-10. CR comparison for the proposed transformation methods.

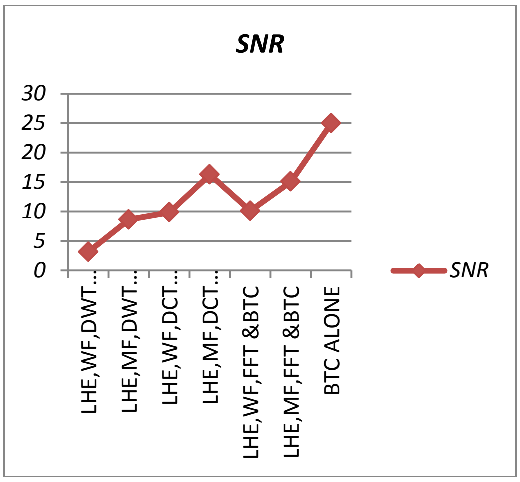

Figure-11. SNR comparison for the proposed transformation methods.

8. EVALUATION

8.1 Evaluation using Compression Ratio

The performance of the compression algorithm was also assessed on the fingerprint images database collected from the Hong Kong Polytechnique University [http://www4.comp.polyu.edu.hk/~cslzang/].

In concurrence with the objective stated in chapter 1, a lossy image compression technique was developed which could achieve greater than 10-to-1 compression ratios while preserving the essential characteristics of the fingerprint image for both mechanized pattern matching and fingerprint identification by human examiners, called the Hybrid fingerprint image compression technique.

The algorithm was assessed with the compression ratio target set by the FBI's WSQ specification 10: 1 to 20: 1. The hybrid compression technique used the BTC along DWT for the quantization phase. For an original image, a block of pixels which requires 4 x 4 x 8 = 92 bits required only 6 + 8 + 8 = 32 bits after compression using BTC. The bit rate is reduced to 16.64%. And RLE is used for the entropy encoding and is a lossless compression technique, typically achieving ratios of 3: 1 for gray scale images. Thus the experiments with HICT attain the Compression Ratio (CR) nearer to the FBI's WSQ specification target. Also, the visual quality of the reconstructed images is very good in this range, which is adequate for fingerprint identification. Fig. 7.10 illustrates the HICT performance at compression of more than10:1.

8.2 Evaluation using MSE and PSNR

PSNR is most commonly used metric to measure the quality of reconstruction of lossy compression codec (e.g. for image compression). When comparing the compression Codecs, PSNR is an approximation to human perception of reconstruction quality. Although a higher PSNR generally indicates that the reconstruction is of higher quality, in some cases it may not. PSNR is calculated from the MSE.

Typical values for the PSNR in lossy image and video compression are between 30 and 50 dB, provided the bit depth is 8 bits, where higher is better. For 16-bit data typically values for the PSNR are between 60 and 80 dB. Acceptable values for wireless transmission quality loss are considered to be about 20 dB to 25 dB.

If the original uncompressed image is in quality level 90 then PSNR is 45.53dB, for quality level 30, the PSNR value is 36.81dB and for the 10% quality level the PSNR value is 31.45dB.The compression algorithm also assessed using the quality metrics MSE and PSNR of the reconstructed images. The experimental results are projected in Table-3 and the result shows that the adopted technique gives MSE and PSNR within the above stated range to conclude that the reconstructed images are in good quality.

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Table-2. Results of the proposed compression techniques.

Proposed compression techniques (CT)	CR	SNR	PSNR	MSE
LHE,WF,DWT &BTC (CT1)	0.41169	30.1255	35.2717	140.64
LHE,MF,DWT &BTC (CT2)	0.43573	18.6226	20.7688	126.4945
LHE,WF,DCT &BTC (CT3)	0.20114	19.8431	21.9894	192.9975
LHE,MF,DCT &BTC (CT4)	0.43651	23.2491	28.3953	199.1018
LHE,WF,FFT &BTC (CT5)	0.44048	20.0699	22.2162	115.2756
LHE,MF,FFT &BTC (CT6)	0.42551	21.0438	27.19	154.7045
BTC ALONE (CT7)	0.40771	24.9259	27.0721	108.3732

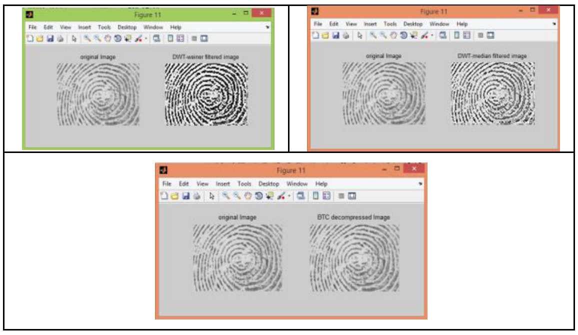

Figure-12. Sample images produced after decompression.

9. CONCLUSION AND FUTURE SCOPE

The Survey of the various Enhancement Algorithms, Restoration Techniques, Transformation methods and Quantization and entropy Encodings has opened up many avenues to study the available concepts and their performance depending on the field of application.

The Hybrid Image Compression Technique (HICT) is designed to produce an algorithm based on the Wavelet Transformation and Block Truncation Coding concept that forms the bases of Compression Algorithm to compress the source fingerprint image to the WSQ target Compression Ratio (CR) of at least 10 to 1 or above. The experiments which have been adopted for the present work with Wavelet transformation and BTC with RLE is first of its kind, in the field of image processing. Thus the results obtained are proved to be effective in analysing fingerprint images. And the method adopted in the present research work significantly produces the CR nearer to 7.25 to 1 with good image quality.

And in future the algorithm is updated or extended for image compression in various fields like Law enforcement, Medical, Military, Scientific research, etc.

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