

Wavelet Based Image Compression Techniques: Comparative Analysis and Performance Evaluation

Umhara Rasool

Department of Electronics and Communication Engineering, Shri Mata Vaishno Devi University, Katra, India

Sanna Mairaj

Department of Electronics and Communication Engineering, Shri Mata Vaishno Devi University, Katra, India

Tamanna Nazeer

Department of Electronics and Communication Engineering, Shri Mata Vaishno Devi University, Katra, India

Suhaib Ahmed

Department of Electronics and Communication Engineering, Shri Mata Vaishno Devi University, Katra, India

Abstract – With the advent of digital information age there has been ever increasing demand of intensive multimedia based web applications, efficient techniques for encoding of images and signals. There are stronger efforts to develop better compression techniques with the sole objective to produce high compression performance while minimizing the amount of image data. Image compression is a technique to reduce redundancy and irrelevancy of image data to enable its efficient transmission and storage. With the help of image compression techniques, we can store more images in a given amount of disk or memory space. We can have lossy or lossless image compression depending upon the application. However, there is degradation in the quality of compressed image in comparison to original image in lossy compression techniques (discrete cosine transform, differential pulse coded modulation etc.). Lossless compression techniques do not deliver high enough compression ratios but exhibit better quality of reconstructed images in comparison to lossy techniques. Wavelet algorithm is one of the indispensable technique to achieve compression while fulfilling approximately all the challenges. It enables multi resolution analysis of data. In this paper, wavelet based compression techniques are studied in detail and a comparison of performance is made in terms of image quality metrics viz. PSNR, MSE, BPP and Compression ratio. Discrete wavelet transform is easier to implement in contrast to continuous wavelet transform. In addition to above, it also provides sufficient information for analysis and synthesis of images with a significant reduction in the computation time. In this paper, Haar, Daubechies, Biorthogonal, Coiflets and Symlet wavelets have been employed to an image and thereof results obtained are analyzed in terms of image quality metrics. In addition to it, a comparison of the image quality has been performed by using four wavelet-based encoding algorithms namely Set Partitioning in Hierarchical Trees (SPIHT), Embedded Zero Tree Wavelet (EZW), Wavelet Difference Reduction (WDR) and Adaptively Scanned Wavelet Difference Reduction (ASWDR). This paper is a guide to the developers to choose better wavelet compression system for their particular applications.

Index Terms – Image Compression, Image Processing, Wavelet Compression, Peak signal to noise ratio(PSNR), Mean squared error(MSE), Bits per pixel(BPP).

1. INTRODUCTION

There has been tremendous upsurge in the amount of data that needs to be efficiently stored and retrieved so that it is put to use effectively. However, the stages involved in carrying out this process poses difficult challenges. Image compression is one of the stages involved in the process of image storage and retrieval that has generated huge interest among researchers. The main objective behind image compression is to effectively reduce redundancy and irrelevancy of the image data so that data is effectively transmitted and stored. While we desire that we should have high compression rates but it needs to be ensured that the reconstructed image should have preserved certain characteristics needed for particular applications after compression has been carried out. It is a known fact that uncompressed image need more transmission bandwidth and storage in comparison to a compressed image [1-3].

Image compression is a fast-evolving field and as such many varieties of compression methods are available. Broadly, we can compress image through lossless or lossy procedures. Lossless process involves compression of image in such a manner that the decompressed image obtained is an exact replica of original image and as such insignificant compression ratio is achieved. In contrast to it, less storage space and saving of transmission bandwidth is achieved at the expense of losing some details of image. Lossy image compressions are useful in applications such as broadcast television, videoconferencing and facsimile transmission in which a certain amount of error is an acceptable trade-off for increased compression performance. Methods for lossless image compression include- Entropy coding, Huffman coding, Bit-plane coding, Run-

length coding, LZW (Lempel Ziv Welch) coding and for lossy compression include Fractal compression, transform coding, Fourier-related transform, DCT (Discrete Cosine Transform) and Wavelet transform.

In this paper, we have discussed image compression based on discrete wavelet transform. Several quality measurement variables like peak signal to noise ratio (PSNR) and mean square error (MSE) have been estimated to determine how well an image is reproduced with respect to the reference image.

2. IMAGE COMPRESSION

A digital image is composed of a finite number of elements, each of which has a particular location and value. An image is defined as a two-dimensional function i.e, a matrix $A(x,y)$ where x and y are spatial coordinates. The amplitude of A at any pair of coordinates (x,y) is called the intensity or gray level of the image at that point. The finite elements of image are referred to as picture elements, image elements or pixels. An image can be converted into digital form by digitizing its coordinates as well as amplitude. The digitization of the coordinate values is called sampling whereas digitizing the amplitude values is called quantization. The steps involved in compression are:

- i. Digitizing of the original image into the string of numbers, p .
- ii. Decomposing the signal ' p ' into sequence of wavelet coefficients, w .
- iii. Applying the threshold to wavelet coefficients w so as to convert it into a new sequence of coefficients, w .
- iv. Applying quantization to sequence w in order to convert it into new sequence, s .
- v. Compression of sequence using entropy encoding.
- vi. Wavelet reconstruction using the original approximation coefficients of level N and the modified detail coefficients of level from 1 to N .

3. DISCRETE WAVELET TRANSFORM

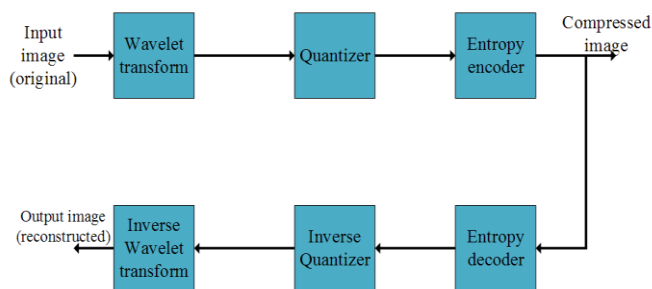


Figure 1 Block Diagram of Image compression process

Wavelet is a versatile set of tools that is applied to the problems of engineering and science such as image denoising, signal

compression, speech recognition etc. Wavelets are functions defined over a finite interval and having an average value of zero. In wavelet transform, a function $S(x)$ is represented as a superposition of a set of such wavelets or basis functions. These basis functions are obtained from a single prototype wavelet called the mother wavelet $\psi(x)$ by dilations (scaling) and translations (shifts).

For each $n, k \in \mathbb{Z}$, we define $\psi_{n,k}(x)$ as

$$\psi_{n,k}(x) = 2^{n/2} \psi(2^n x - k) \quad (1)$$

$\psi(x)$ is a wavelet and the collection $\{\psi_{n,k}(x)\}$ $n, k \in \mathbb{Z}$ is a wavelet orthonormal basis on \mathbb{R} and ψ must satisfy

$$\int \psi(x) dx = 0. \quad (2)$$

Wavelet are predominantly applied in the field of image processing owing to its special feature i.e, flexible window size. It employs narrower window at high frequency for a better time resolution while using wider window at low frequencies for better frequency resolution. We would like to have discrete representation of time and frequency i.e, the discrete wavelet transform (DWT) as image compression deals with the sampled data.

The purpose of wavelet transform is to change the data from time-space domain to time-frequency domain which makes better compression results. Basic types of wavelets are

- i. Haar wavelet transform.
- ii. Daubechies wavelet transform.
- iii. Symlet wavelet transform.
- iv. Biorthogonal wavelet transform.
- v. Coiflets wavelet transform.

These various transforms are implemented to observe how various mathematical properties such as symmetry, number of vanishing moments and orthogonality differ the result of compressed image. The Daubechies wavelets are orthogonal and so are Coiflets. Symlets have the property of being close to symmetric. The biorthogonal wavelets are not orthogonal but possess the symmetric property.

3.1 Principle behind Wavelet Transform

The discrete wavelet transform is usually implemented by using a hierarchical filter structure. It incorporates analysis bank and synthesis bank. The analysis bank consists of low pass and high pass filter to separate the input signal into frequency bands (down sampling) [5]. It breaks the input signal into 4 lower resolution components. They are represented as:

- i. LL (low resolution approximate image)
- ii. HL (intensity variation along column, horizontal edge)

- iii. LH (intensity variation along row, vertical edge)
- iv. HH (intensity variation along diagonal)

The LL can further be decomposed to obtain another level of division. This process can be repeated to perform a desired number of division levels [4].

After decomposition, we compute reconstructed image using the original approximation coefficients of level N and the modified detail coefficients of level from 1 to N.

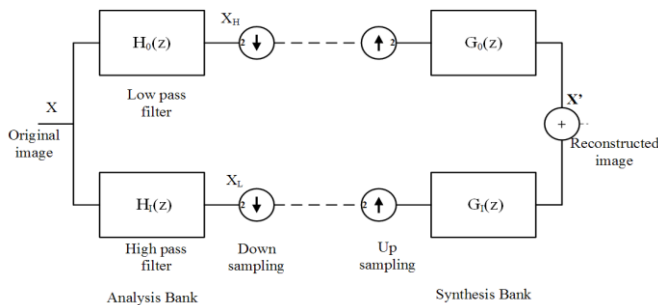


Figure 2. Filter structure and associated wavelet [6]

4. ENCODING OF DECOMPOSED IMAGE

EZW encoder is normally employed in conjunction with the wavelet transform. After the image is passed through filter bank, it encodes the decomposed image. It is based on zero-tree concept for significant-map information and uses 'parent-child' dependencies between sub-band coefficients at same spatial location [9].

Other encoding algorithm SPHIT, an extension of EZW notably improves the performance of its predecessor by changing the way subsets of coefficients are partitioned and how refinement of information is expressed [7].

WDR is used to generate an embedded bit stream. It consists of 3 basic steps: Discrete Wavelet Transform, Differential Coding and Binary coding. Significant transform value is indexed to facilitate Region of Interest (ROI) and compression process. It is employed where transmission is to be carried over small bandwidth.

ASWDR is the enhanced version of WDR algorithm addition with the new scanning orders. It dynamically adapts to the location of edge details in intention to reduce the length of symbol string for encoding the distances and enhances the resolution of edges [8].

5. PERFORMANCE METRICS

In order to determine the allegiance of a recovered image to the original image, we normally find the difference between the original and reconstructed values.

If $\{x_n\}$ is the source sequence and $\{y_n\}$ is the reconstructed sequence, the squared error measure is given by

$$d(x, y) = (x - y)^2 \quad (3)$$

and the absolute difference measure is given by

$$d(x, y) = |x - y| \quad (4)$$

Mean squared error (MSE), δ_d^2 can be expressed as

$$\delta_d^2 = 1/N \sum (x_n - y_n)^2 \quad (5)$$

Other metric that we are interested in is the size of the error relative to the signal. It can be expressed as the ratio of the average squared value of the source output and the MSE. This is called the *signal-to-noise-ratio* (SNR).

$$\text{SNR} = \delta_x^2 / \delta_d^2 \quad (6)$$

However, PSNR is the most predominant metric used to evaluate image compression quality. The ratio of peak value of the signal to the MSE is called the peak-signal-to-noise ratio (PSNR) and is calculated by the following equation:

$$\text{PSNR} = 10 \log_{10} x_{\text{peak}}^2 / \delta_d^2 \quad (7)$$

6. IMPLEMENTATION AND PERFORMANCE EVALUATION

In order to compare the quality of compression for different types of wavelets, we have used the standard sample image – Lena (Fig. 3).

From the table I, it is obvious that biorthogonal spline wavelet achieves better compression result than other type of wavelets and among these haar wavelet has worst performance.

Wavelet	Compression ratio	PSNR(dB)
Haar	2.66	56.0258805
Symlet (sym4)	2.08	56.4685950
Daubechies (db4)	2.27	56.7906157
Biorthogonal splines (bior4.4)	1.92	56.2370440
Coiflet (coif4)	2.05	56.6111237

Table 1 Comparison of Compression Results by Using Different Wavelets



Figure 3 Original Lena Image used as reference image

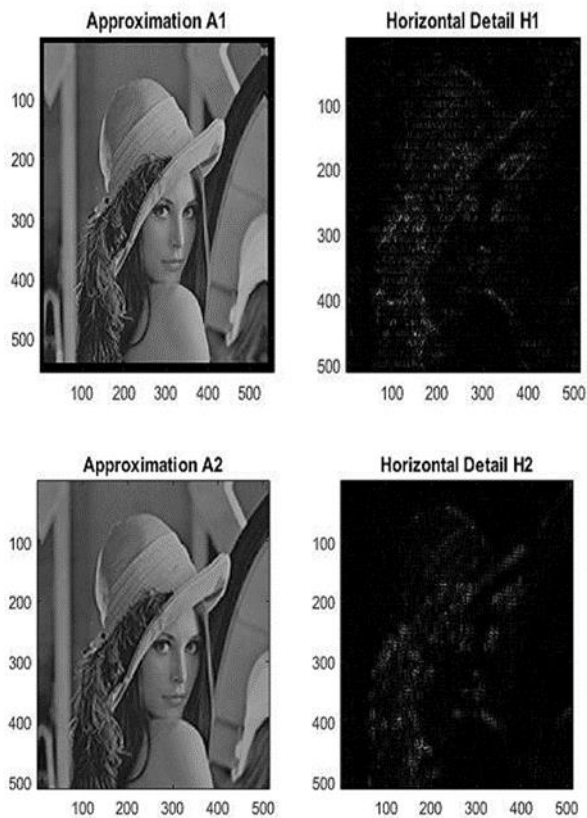


Figure 4 Wavelet Decomposition of an Image Component.

All the four encoding algorithms in conjunction with haar wavelet and symlet wavelet have been employed on sample standard image, Barbara .bmp and results thereof obtained are given in table II and III. From the tables, it is observed that WDR outperforms other three algorithms with its better compression ratio and bits per pixel(BPP).

Algorithm	Compression ratio	MSE	PSNR(dB)	BPP
EZW	4.03	0.99	48.194589	0.32
SPIHT	0.96	0.99	48.194589	0.08
WDR	4.47	0.99	48.194589	0.36
ASWDR	4.39	0.99	48.194589	0.35

Table 2 Comparison of results by using different encoding algorithms (Haar wavelet)

Algorithm	Compression ratio	MSE	PSNR(dB)	BPP
EZW	3.59	1.19	47.3656602	0.29
SPIHT	0.88	1.19	47.3656602	0.07
WDR	3.94	1.19	47.3656602	0.32
ASWDR	3.88	1.19	47.3656602	0.31

Table 3 Comparison of results by using different encoding algorithms (Symlet wavelet)

7. CONCLUSION

Discrete wavelet transform provides sufficient high compression ratios with no appreciable degradation of image quality a comparative analysis on image compression is

performed by using different variants of mother wavelet. Among all these wavelets, it is analyzed that biorthogonal achieves better compression results. From the other comparison results show that WDR is better among these four encoding algorithms as it allows to preserve finer details of the image while maintaining lower bit rate.

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