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A Comparative Analysis on the Wavelet-Based Image Compression Techniques

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Abstract—As the coming era of digitized image information, it is critical to produce high compression performance while minimizing the amount of image data so the data can be stored effectively. Compression using wavelet algorithm is one of the indispensable techniques to solve this problem. The Wavelet Algorithm contains transformation process, quantization process, and lossy entropy coding. Wavelets are functions which allow data analysis of signals or images, according to scales or resolutions and it provides a powerful and remarkably flexible set of tools for handling fundamental problems in science and engineering, such signal compression, image de-noising, image enhancement and image recognition. The aim of this paper is to compare the image quality by using 4 wavelet-based image compression techniques; namely Set Partitioning In Hierarchical Trees (SPIHT), Embedded Zerotree Wavelet (EZW), Wavelet Difference Reduction (WDR) and Adaptively Scanned Wavelet Difference Reduction (ASWDR). While for analysis, Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), Compression Ratio (CR) and Bit Per Pixels (BPP) analysis are used. From the obtained results, it shows that WDR outperform in terms of compression efficiency.

Index Terms—Wavelets, SPIHT, EZW, WDR, ASWDR

1 Introduction

WAVELET is a flexible tool with rich mathematic content and has enormous potential in many applications and greatly being used in the field of digital images. Wavelet algorithm work as signal processing in such a way like the human vision do. It provides a much more precisely in digital image, movies, color image and signal [1]. It also has widely used in data compression, fingerprint encoding and also image processing.

Wavelet will give different perception when something is observed at different location. Like the eyes of human do, for example, when the forest is observed from the above, it is spotted as a splash of green, while if we observe in moving vehicle, it can be observed as a flashing forest. Conversely, if we observe the forest by walking, we can see the forest in more detail, such as the leaves, the root, trunk as well as the structure of the trunk.

Wavelet has special features in which it has flexible window size to determine accurately either time or frequency. It use narrower window at high frequency for a better resolution while using wider window at low frequencies for better frequency resolution.

2 Wavelet Features

Wavelet coefficient has good time resolution at higher frequency to capture the image and good frequency resolution at lower frequency to capture image background. Human eyes is less sensitive to high frequency but very sensitive to low frequency [2].

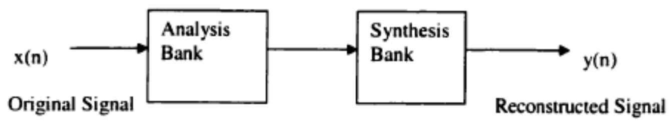

Fig. 1. Filter bank [1]

The filter banks in Wavelet consist of analysis bank and synthesis bank (Refer to Figure 1). The analysis bank has a low pass and high pass filter to separate the input signal into frequency band (downsampling) [4]. It breaks the input signal into 4 lower resolution components (Refer to Figure 2). They are given as LL (low resolution approximate image), HL (intensity variation along column, horizontal edge), LH (intensity variation along row, vertical edge) and HH (intensity variation along diagonal). The LL can further be divided to obtain another level of division. This process can be repeated to perform a desired number of division levels [3].

The quantization is done on the decomposed image on different component to maximizing the amount of necessitate detail and ignoring 'not-so-wanted' details. Here, some coefficient value for pixel in image are thrown out or set to zero [5]. This is called as the thresholding process and it give some smoothing effect to the image.

In order to compress the image, Wavelet analysis can be used to divide the information of an image into approximation and detail sub-signals. The approximation sub-signal shows the general trend of pixel values, and three detail sub-signals show the horizontal, vertical and

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diagonal details or changes in the image. If these details are very small then they can be set to zero without significantly changing the image. The value below which details are considered small enough to be set to zero is known as the threshold. The greater the number of zeros the greater the compression that can be achieved [6].

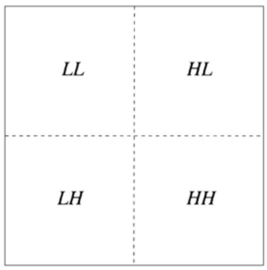

Fig. 2. Ideal decomposition of 2D spectrum [6]

In inverse of analysis bank, the synthesis bank will do the upsampling to reconstruct the original fine scale coefficient by combining the scale and wavelet coefficients at lower coarser scale. During upsampling the value of zero will be inserted between 2 coefficients because during the downsampling, the every second coefficient is thrown away. Figure 3 show the general process of downsampling and upsampling in Wavelet packet composition.

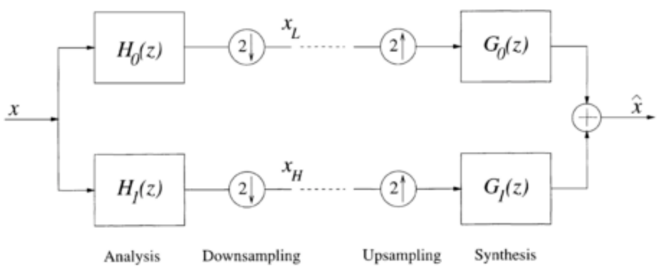

Fig. 3. Upsampling and downsampling in Wavelet packet composition [6]

Wavelet algorithm enables the computer to decompose an image into various levels with different-value resolution. The apparent advantage is it enables to isolate and manipulate data with specific properties. For example, more vertical details is keep instead of keeping all the horizontal, diagonal detail when the image has more vertical aspect[7]. This will allow some unwanted value of horizontal and diagonal detail without degrading the quality of image in human perception.

The amount of information retained by an image after compression and decompression is known as the energy retained and this is proportional to the sum of the squares of the pixel values. If the energy retained is 100% then the compression is known as lossless as the image can be reconstructed exactly. This occurs when the threshold value is set to zero, meaning that the detail has not been changed. If any values are changed then energy will be lost and this is known as lossy compression. Ideally, during compression the number of zeros and the energy retention will be as high as possible. However, as more zeros are obtained more energy is lost, so a balance between the two needs to be found.

2.1 Wavelet-Based Algorithm

There are many Wavelets generic being introduced nowadays. Sophisticated wavelets produce smoother and more satisfactory compressed image. It makes no assumption concerning periodicity of the data. As a result, Wavelets are suitable for demonstrating sharp changes or even discontinuities. Some of the common Wavelet methods used in image processing are Haar Wavelet, EZW and SPHIT. While the extended versions that already being well accepted in committee are WDR and ASWDR. Wavelets has offer great compression ratio without harming the image quality and it became a solemn challenger to DCT[8].

2.2 Haar Wavelet

Haar Wavelet is a certain sequence of rescales 'square-shaped' function and the simplest wavelet. It is not continuous therefore not differentiable, thus giving a good analysis on signal with sudden transition or discontinuity. As can be seen in Figure 4, Haar starts by averaging the pixel together to get new lower resolution image. To recover the original pixel from the averaged pixels some detail coefficient are stored. Repeating this process on the averages gives the full decomposition. Some of the notable advantages of Haar are, it gives the best performance in term of computation time, memory efficient and can exactly reversible without the edge effect [9].

2.3 Embedded Zerotree Wavelet (EZW)

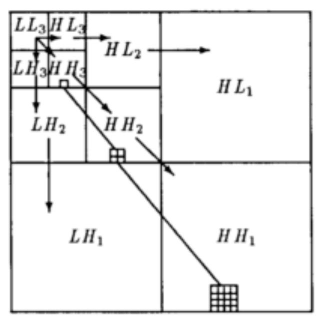

Fig. 4. Parent child dependencies of subbands [10]

EZW was the first image coder that use zero-tree concept for significant-map information. It uses 'parent-child' dependencies between subband coefficients at same spatial location (Refer to Figure 4). It generates encoded bits in specific order of importance. It finds the largest coefficient magnitude in 8 x 8 fixed block size image. Then initial threshold is chosen based on the coefficient interval. Every single value of the pixel is then examined in the first dominant pass to determine the sign and the reconstruction value. It continues with first subordinate pass and second dominant pass with new threshold value to get more finer reconstructed magnitude value. EZW is using Discrete Wavelet Transform (DWT) to transform the image and embedded coding is done by using Successive Approximate Quantization (SAQ) [2] [10] .

2.4 Set Partitioning In Hierarchical Trees (SPIHT)

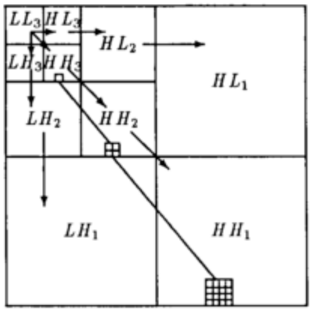

Fig. 5. Examples of parent-offspring dependencies in spatiall orientation tree [11]

SPHIT algorithm is an extension of the EZW algorithm. It significantly improved the performance of its predecessor by changing the way subsets of coefficients are partitioned and how refinement information is expressed (Figure 5). The uniqueness of SPHIT is its compactness. The bitstream from SPHIT algorithm is so compact that passing it through an entropy coder would only produce very insignificant gain in compression. No ordering information is explicitly transmitted to the decoder. As an alternative, the decoder reproduces the execution path of the encoder and recovers the ordering information [11]. However, SPIHT have some limitation such as high-memory requirement, frequently repeat seeking process and also complex management of list.

2.5 Wavelet Different Reduction (WDR)

WDR is used to ease the transmission over small bandwidth by generating 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. After applying wavelet transform, difference reduction method based on their successive differences is applied. Encoding can be stopped at any point, allowing a target rate to be met accurately. To improve the compression performance, arithmetic coding technique is used. WDR produce low bit rate reconstruct image in affect of the decoding process can be terminated at any point.

2.6 Adaptive Scanned Wavelet Different Reduction (ASWDR)

ASWDR is the enhanced version of WDR algorithm addition with the new scanning orders that 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. The ASWDR method is well described in [12]. ASWDR suggests a better prediction scheme that will significantly reduce the coding output of WDR. The advantage of ASWDR is can protect the details at low bit rates and it was beneficial for medical imaging.

Table 1 shows the summary of five wavelet-based algorithms.

TABLE 1
SUMMARY ON FIVE WAVELET-BASED ALGORTHMS

Algorithm	Technique	Advantage	Limitation
HAAR[9]	'square-shaped' function	Good analysis on signal with sudden transition or discontinuity. Averaging the pixel together to get new lower resolution image.	Unpleased compression rate
EZW[10]	zero-tree concept for significant-map information	Finer reconstructed magnitude value.	Sub-image level encoding is not possible. Computational complexity is high.
SPIHT[11]	parent-offspring dependencies is spatial orientation tree	Compactness.	High-memory requirement, frequently repeat seeking process and also complex management of list
WDR[13]	3 basic steps: Discrete Wavelet Transform, Differential Coding and Binary coding	Encoding can be stopped at any point, allowing a target rate to be met accurately.	Limited scanning order
ASWDR[12]	enhanced version of WDR algorithm with the new scanning orders	Improve the subjective and objective perceptual qualities of compressed images. Better edge preservation	Localize noise

3 EXPERIMENTAL RESULTS ON WAVELET-BASED COMPRESSION METHODS

There are three sample standard images used for the experiment; Lena.bmp, Cameraman.tif and Barbara.bmp. The image dimension of Lena.bmp is 256 x 256, while Cameraman.tif and Barbara.bmp is 512 x 512. In this analysis, the images are compressed by Set Partitioning In Hierarchical Trees (SPIHT), Embedded Zerotree Wavelet (EZW), Wavelet Difference Reduction (WDR) and Adaptively Scanned Wavelet Difference Reduction (ASWDR).

The quantitative and perceptual quality measures of the compression performance are done on the sample image. Qualitative measure is done via compression performance, that is evaluated using compression ratio (CR) and Bit-Per-Pixel (BPP). The compression ratio means the ratio of the original image size over the compressed image size, while the BPP is the number of bits required to store one pixel of the image [14].

For perceptual quality, Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) are used [15]. MSE represent the mean squared error between compresses and the original image, while PSNR stand for a measure of the peak error and is expressed in decibels [16].

Fig. 6. Compression of Lena (a) original (b) SPIHT compression (c) EZW compression (d) WDR compression (e) ASWDR compression

Fig. 7. Compression of Cameraman (a) original (b) SPIHT compression (c) EZW compression (d) WDR compression (e) ASWDR compression

TABLE 2
QUANTITATIVE AND PERCEPTUAL QUALITY MEASURES OF COMPRESSION PERFORMANCE ON LENA IMAGE

Methods	Compression ratio	PSNR	MSE	BPP
SPIHT	2.3239	32.1101	40.0013	0.1859
EZW	3.4946	32.8449	33.7743	0.2796
WDR	3.7579	32.8449	33.7743	0.3006
ASWDR	3.6617	32.8449	33.7743	0.2929

TABLE 3
QUANTITATIVE AND PERCEPTUAL QUALITY MEASURES OF COMPRESSION PERFORMANCE ON CAMERAMAN IMAGE

Methods	Compression ratio	PSNR	MSE	BPP
SPIHT	2.5791	32.5701	35.9809	0.2063
EZW	7.4116	37.5756	11.3637	0.5929
WDR	7.8918	37.5756	11.3637	0.6313
ASWDR	7.7354	37.5756	11.3637	0.6188

Figure 6 and Table 2 shows the subjective and objective compressions performance of Lena image respectively. It is difficult to observe any differences at all between any of these images. This illustrates that all compression methods produce equally good compressions at moderately high bit rates.WDR shows the greatest performance in compression ratio, PSNR, MSE and BPP compared to another 4 algorithm. In almost every case the PSNR and MSE value for EZW, WDR and ASDWR is the same. These numerical results are consistent with the increased preservation of details within EZW, WDR and ASDWR.

Non-expert observer (engineering student) has commented that WDR and ASWDR compressed images (as can be seen in Figure 7) appear sharper than SPHIT and EZW compressed images. Human Visual System center of attention is on edges when analyzing images. The ASWDR and WDR compressions have higher edge correlation than SPIHT compression. The WDR compression ratio is slightly higher than ASWDR edge correlation as can be seen on Table 3.

Fig. 8. Compression of Barbara (a) original (b) SPIHT compression (c) EZW compression (d) WDR compression (e) ASWDR compression

TABLE 4
QUANTITATIVE AND PERCEPTUAL QUALITY MEASURES OF COMPRESSION PERFORMANCE ON BARBARA IMAGE

Methods	Compression ratio	PSNR	MSE	BPP
SPIHT	5.4680	28.8597	84.5496	0.4374
EZW	15.5819	33.9452	26.2158	1.2466
WDR	18.5459	33.9452	26.2158	1.4837
ASWDR	18.0099	33.9452	26.2158	1.4408

By referring to Figure 8 and Table 4, it can be noticed that the compression ratio and BPP of WDR for Barbara image is clearly superior to both ASWDR and SPHIT. While PSNR and MSE value for EZW, WDR and ASWDR retain the same.

CONCLUSION

Based on the four quality measures done on four type wavelet based compression algorithms, it shows that WDR is a promising method that provide improved preservation of details at low bit rates. Protecting details at low bit rates is crucial for sensitive data such as remote medical diagnosis via rapid transmission of compressed image and rapid retrieval of image in databases.

The tree-based character of all wavelet-based algorithms applies to identical subband coding. Therefore, modification on prediction procedure should be performed to construct new scanning order that can eliminate blocking or edge effect. Extended research is a must to produce better quality of image.

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