Image Compression Algorithms using Wavelets: a review

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Abstract – Wavelet transformation is powerful feature for the signals and frequency analysis of an image. Wavelet family emerged as an advantage over Fourier transformation or short time Fourier transformation (STFT) .Image compression not only reduces the size of image but also takes less bandwidth and time in its transmission. This paper uses two image compression algorithms SPIHT and EZW for comparing the quality of images and the quality of images is compared by taking PSNR and MSE of images. Analysis of the quality measures have been carried out to reach to a conclusion.

Keywords –*SPIHT, EZW, MSE, PSNR, LSP, LIP, ZTR*

I. INTRODUCTION

Image compresssion is divided into two categories, lossless compression[1] and lossy compression. In lossless compresssion, the image is reconstructed by using image information and while lossy compression is allowed loss when the image information is reconstructed. In general, the image is required to fully reconstruct without loss. However, the lossy image is used for obtaining a higher compressed ratio.

   For a compressed image, the number of bits used in the compressed representation of the image divided by the number of pixels in the image is defined as bit rate achieved by the compressor, measured in bits/pixel. The image can be compressed in such a way by using quality metric or resolving several distortion inorder to match the original image in lossy compression. Peak Signal to Noise Ratio(PSNR) is a quality metric, because increasing PSNR values indicates increasing reconstructed image fidelity.

$$PSNR = 10 \ \lg \left[\frac{MN \ (2^B - 1)^2}{\sum_{m=0}^{M-1} \sum_{N=0}^{N-1} [g(m,n) - f(m,n)]^2} \right]$$

Here M and N denote the image width and height, respectively; f(m,n) and g(m,n) denote original and reconstructed iamge; and B denotes the dynamic range(in bit) of the original image.

   SPIHT[2] [3] algorithm was introduced by Said and Pearlman[4] and is improved and extended version of Embeded Zerotree Wavelet(EZW) coding algorithm introduced by Shapiro[5][6]. Both algorithms work with tree structure, called Spatial Orientation Tree (SOT), that defines the spatial relationships among wavelet coefficients in different decomposition subbands. In this way, an efficient prediction of significance of coefficients based on significance of their parent coefficients is enaïbled.

   SPHIT is a low-complexity progressive image compressor. This enhanced implementation of a zerotree algorithm efficiently encodes zerotrees with a relatively modest level of complexity and produces an embedded bitstream. A higher image compression ratio can not be obtained by using SPHIT algorithm only, it can be obtained by using a lossy algorithm based on SPIHT encoding algorithm is proposed in this paper. Firstly, the wavelet coefficients are divided into sevral blocks, then the importance of different blocks are by adopting SPHIT algorithm of different blocks are encoded by adopting SPHIT algorithm of different bit rate, in order to improve the compression ratio.

II. FRAME OF SIMULATING SYSTEM

According to the importance of the wavelet coefficients blocks, the simulation system consists of three parts: a Discrete Wavelet decomposition of image data, a SPHIT encode module which performs the coding of wavelet coefficients in the block by bit rate and a bit allocate module which controls the SPHIT encode module that input the bit stream as shown in the fig.1.
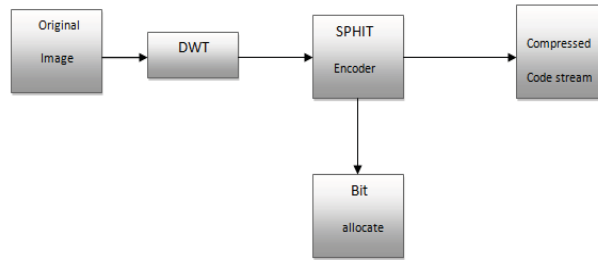
Fig. 1.   SPHIT Encode Structure

III. SPIHT ALGORITHM

The SPIHT algorithm was introduced by Said[7] and Pearlman. It is simply image compression algorithm which is powerful, efficient and yet computational.
For a different types of image the highest PSNR values can be obtained using given compression ratio by using this algorithm. It provides a better comparison standard for all subsequent algorithms. SPIHT stands for Set Partitioning in Hierarchical Trees. SPIHT was designed for optimal progressive transmission, as well as for compression. One of the important features of SPIHT was designed for optimal progressive transmission, as well as for compression. The another important features of SPIHT is the quality of the displayed image is the best at any point during the decoding of an image, that can be achieved for the number of bits input by the decoder up to that moment
    The wavelet coefficients can be reffered as $c_{i,j}$. In a progressive transmission method, the decoder starts by setting the reconstruction image to zero. It then inputs (encoded) transform coefficients, decods them, and uses them to generate an improved recontruction image. The main aim in progressive transmission is to transmit the most important image information first. SPHIT uses the mean squared error (MSE) distortion measure.

$$MSE = \frac{\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}(\hat{x}_{i,j} - x_{i,j})^2}{\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}(x_{i,j})^2},$$

Where, N is total number of pixels. So the largest coefficients contain the information that reduces the MSE distortion.

A. SPIHT Coding

        It is important to have the encoder and decoder test sets for significance in the same way, so the coding algorithm uses three lists called list of significant pixels (LSP), list of insignificant pixels (LIP), and lists of insignificant sets (LIS).

1. Initialization: Set n to [$\log_2 \max_{i,j}(c_{i,j})$] and transmit n. Set the LSP to empty. Set the LIP to the coordinates of all the roots (i,j)_ H. Set the LIS to the coordinates of all the roots (i,j)_ H that descendants.

2. Sorting pass
        2.1 for each entry (i,j) in the LIP do:
        output $S_n(i,j)$;
        if $S_n(I,j) = 1$, move (i,j) to the LSP and the sign of $c_{i,j}$;
                for each entry (i,j) in LIS do:
        if the entry is of type A, then
                output $S_n(D(i,j))$;
            if $S_n(D(i, j) = 1$, then

        for each (k,l)__ O(i,j) do:

            output S_n (k,l);

            if $S_n(k,l) = 1$, add (k,l) to the LSP,

output the sign of $C_{k,l}$;

if $S_n(k,l) = 0$, append (k,l) to the LIP;

if L(i, j) not equal to 0, move (i, j) to the end

of the LIS, as a type-B entry, and go to step

else,remove entry (i,j) from the LIS;

if the entry is of type B, then

Output $S_n(L(i, j))$;

if$S_n(L(i,j)) = 1$, then

append each (k, l)__ O(i, j)to the

LIS as a type-A entry:

Remove (i,j) from theLIS:

3. Refinement pass: for each entry (i,j) in the LSP, except those included in the last sorting pass (the one with the same n), output the nth most significant bit of $|c_{i,j}|$;

4. Loop: decrement n by 1 go to step 2 if needed.

IV. EZW ALGORITHM

The EZW algorithm was one of the first and powerful algorithms based on Wavelet based Image compression. The algorithms were created depending upon the fundamental concepts of EZW. The EZW algorithm was introduced in this paper of Shapiro. The expansion of EZW is Embedded Zerotree Wavelet. The core of the EZW compression is the exploitation of self-similarity across different scales of an image wavelet transform. In other wordsEZW approximates higher frequency coefficients of a wavelet transformed image. The degradation of the image can be occurred in a particular location of the restored image on discarding a high frequency coefficient as the wavelet transform coefficients contain information about both spatial and frequency content of an image. Here, the threshold is used to calculate a significance map of significant and insignificant wavelet coefficients. Zerotrees are used to represent the significance map in an efficient way. The main steps are as follows :

1. Initialization: Set the threshold T to the smallest power of 2 that is greater than $\max_{(i,j)} |c_{(i,j)}|/2$, where $c_{(i,j)}$ are the wavelet coefficients.
2. Significance map coding: Scan all the coefficients in a predefined way and output a symbol when $|c_{(i,j)}|>2$. When the decoder inputs this symbol, it sets
3. Refinement: Refine each significant coefficients by sending one more bit of its binary representation. When the decoder receives this, it increments the current coefficient value by $\pm 0.25T$.
4. Set T=T/2, and go to step 2 if more iterations are needed.

A. *The Wavelet transform*
The wavelet transform is applied on each component of the Luminance and Chrominance (LC) spaces (YCrCb, YUV, YIQ). Several decomposition filters have been taken into consideration. A number of sub bands which consist of coefficients, describe the horizontal and vertical spatial frequency characteristics of the original image.

B. *EZW Coding*
A Wavelet coefficient $c_{i,j}$ is considered insignificant with respect to the current threshold T if $|c_{i,j}|=T$. The zerotree data structure can be constructed from the following experimental result: If a wavelet coefficient at a coarse scale (i.e., high in the image pyramid) is insignificant with respect to a given threshold T, then all of the coefficients of the same orientation in the same spatial location at finer scales (i.e., located lower in the pyramid) are likely to be insignificant with respect to T. In each iteration, all the coefficients are scanned in the order shown in fig. 2 . This guarantees that when a node is visited, all its parents will already have been scanned.

Each coefficient visited in the scan is classified as a zerotree root (ZTR), an isolated zero(IZ), positive significant (POS) or negative significant (NEG). A zerotree root is a coefficient that is insignificant and all its descendants (in the same spatial orientation tree) are also insignificant. Such a coefficient becomes the root of a zerotree. It is encoded with a special symbol (decoded by ZTR). When the decoder inputs a ZTR symbol, it assigns a zero value to the coefficients and to all its descendants in spatial orientation tree. Their values get improved in subsequent iterations. The fig 3 illustrates this classification.
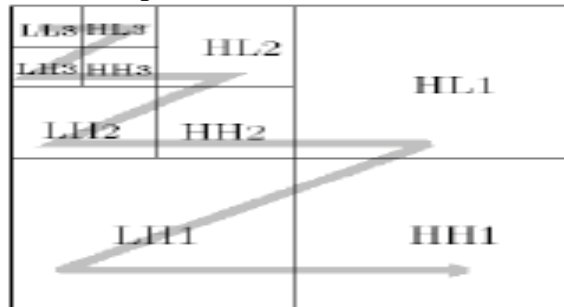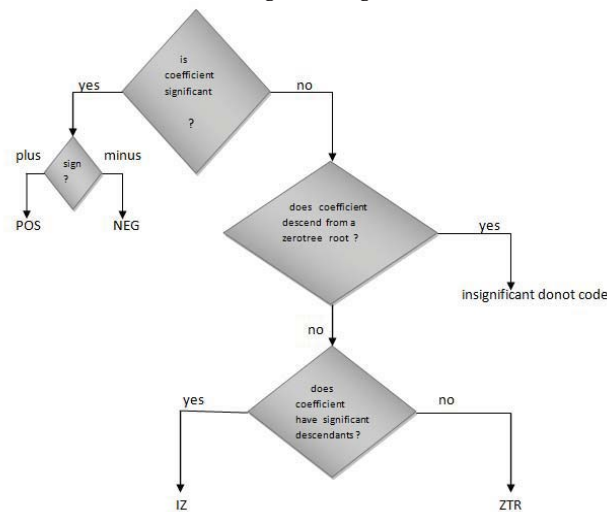

Fig1. Scanning of Zerotree

Fig2. Classifying a Coefficient

Two lists are used by the encoder (and also by the decoder, which works in lockstep) in the scanning process. The dominant list contains the coordinates of the coefficients that have not been found to be significant. They are stored in the order scan, by pyramid levels, and within each level by subbands. The subordinate list contains the magnitudes of the coefficients that have been found to be significant. Each list is scanned once per iteration. Iteration consists of a dominant pass followed by a subordinate pass. In the dominant pass, coefficients from the dominant lists are tested for significance. If a coefficient is found significant, then i) its sign is determined,ii) it is classified as either POS or NEG,iii) its magnitude is appended to the subordinate list, and iv) it is set to zero in memory (in the array containing all the wavelet coefficients). The last step is done so that the coefficient does not prevent the occurrence of a zerotree in subsequent dominants passes at smaller thresholds. At the end of the subordinate pass, the encoder sorts the magnitudes in the subordinate list in decreasing order. The encoder stops the loop when a certain condition is met and the decoder stops decoding when the maximum acceptable distortion has been reached.

V. EXPERIMENTS

The images Lena, Baboon, Cameraman, Peppers, Barbara and Bridge are used for experiments. PSNR (Peak Signal to Noise Ratio) values and MSE(Mean Square Error) values are found by using the above experiment result. The result that got by using SPHIT technique are shown in fig.4 and fig.5   .

Fig. 2.   SPHIT Compression of Lena ,Baboon & Camereman image

Fig. 3.   SPHIT Compression of Peppers, Barbara &Bridge image

The fig.6   and   fig.7   show the results that got by using EZW technique. A fully embedded bit stream is produced by using EZW. Discrete wavelet transform, Zerotree coding of wavelet coefficients and successive approximation quantization are the main features of EZW. A series of decisions in EZW have been taken to distinguish the reconstructed image from null image.

Fig. 4.   EZW Compression of Lena, Baboon & Camereman image

Fig. 5.   EZW Compression of Peppers, Barbara &Bridge image

VI. PERFORMANCE ANALYSIS

The above algorithms are compared and performance is evaluated. The PSNR and MSE values for the images are calculated by using the following formula. It is shown in the table 1 and table 2.

$$ \text{PSNR} = 10 \log_{10} \left(\frac{255^2}{\text{MSE}} \right) $$

$$ \text{MSE} = \frac{\sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (\hat{x}_{i,j} - x_{i,j})^2}{\sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (x_{i,j})^2}, $$

The SPHIT method is the advance method for image compression. It requires keen attention because it provides highest image quality, progressive image transmission, fully embedded coded file. It is effective in broad range of reconstruction qualities because of its embedded coding process, simple quantization, exact bit rate coding and Error protection.

TABLEI   PSNR AND MSE VALUES FOR SPHIT

IMAGE	PSNR	MSE
Lena	39.85	6.7242
Cameraman	35.56	18.0679
Bridge	29.78	68.4667
Barbara	36.62	14.1501
Pepers	37.81	10.7597
Baboon	28.53	91.2663

By using discrete wavelet transformation, EZW provides compact multiresolution images, zerotree coding of the significant wavelet coefficients providing compact binary maps, adaptive multilevel arithmetic codimg and capability of maating an exact bit rate with corresponding rate distortion function (RDF).

TABLEII PSNR AND MSE VALUE FOR EZW

IMAGE	PSNR	MSE
Lena	26.21	155.6583
Cameraman	24.43	234.2509
Bridge	23.68	278.6882
Barbara	22.92	332.1073
Pepers	23.59	89.8794
Baboon	22.19	134.7829

The compression ratio is taken as 2:1 to reduce the time needded for subjective testing. The comparison of SPHIT and EZW by using PSNR and MSE is shown in fig.8 and fig.9 .
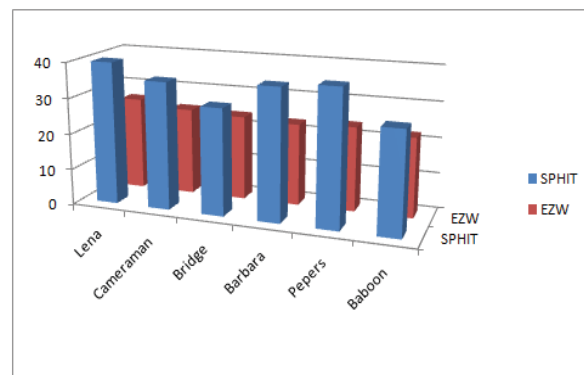

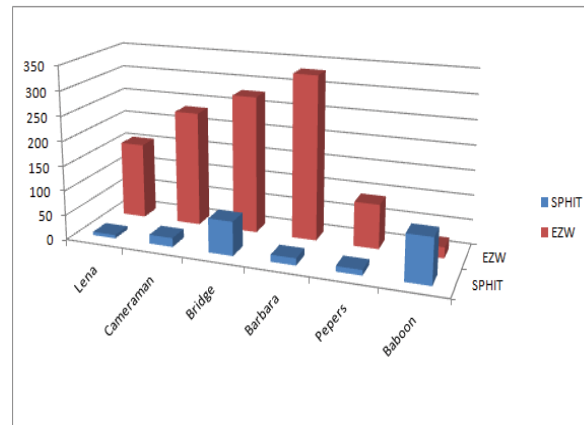Fig. 6.   Comparison for PSNR value for SPHIT and EZW

Fig. 7.   Comparison for MSE value for SPHIT and EZW

IX. CONCLUSION AND FUTURE SCOPE

We have applied various wavelets from wavelet family on SPIHT as well as EZW and observed different results. On comparison, we discovered that SPIHT shows better PSNR and MSE performances on the various test images, as we can see from the results the PSNR values are greater in case if SPIHT and MSE are lesser, and in case of EZW algorithm the MSE values are very high in comparison to MSE obtained from SPIHT.EZW has used Huffman coding and SPIHT has used embedded coding furthermore, we can use SPIHT with Arithmetic coding. We can also try to reduce running time of EZW algorithm which takes longer to run than SPIHT.

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