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Minimum entropy based Lossless Image Compression using Predictive Coding and Integer Wavelet Transform

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***Abstract—* In this paper, for lossless compression of the grey-scale mages a hybrid scheme is proposed . This scheme combines the integer wavelet transforms (IWT) and predictive coding. Here we will apply first the predictive coding and then integer wavelet transform to obtain sub bands of the image as an output of the lifting scheme. Transmission of data, efficient storage of data, management and retrieval of the voluminous data produced by the medical images has nowadays become increasingly complex. This thesis presents an adaptive lifting scheme, which performs integer-to-integer wavelet transform, for lossless image compression. In this paper we will calculate some parameters such as compression ratio and scaled entropy to evaluate the performance of our proposed technique when applied to different test images.**

***Index Terms*—- Lossless Image Compression, Lifting Scheme., Haar Wavelet Transform, Entropy, Subband Coding, Predictive Coding, Second Order Predictor.**

I. INTRODUCTION

Compression offers a means to reduce the cost of storage and increase the speed of transmission, thus medical images have attained lot of attention towards compression. These images are very large in size and require lot of storage space. Image compression can be lossless and lossy, depending on whether all the information is retained or some of it is discarded during the compression process. In lossless compression, the recovered data is identical to the original, whereas in the case of lossy compression the recovered data is a close replica of the original with minimal loss of data. There has been a lot of research going on in lossless data compression. The most common lossless compression algorithms are run-length encoding, LZW, DEFLATE, JPEG, JPEG 2000, JPEG-LS, LOCO-I etc. Lempel–Ziv–Welch is a lossless data compression [9].

The first two methods eliminate the frequent flushing of dictionary, thus lowering processing time and the third method improves the compression ratio by reducing number of bits transferred over the communication channel. JPEG is most commonly used lossy compression technique for photographic images which can be converted into lossless by performing integer reversible transform. Lossless compression in JPEG [7] is achieved by performing integer reversible DCT (RDCT) instead of the floating point DCT used in original JPEG on each block of the image later using lossless quantization. Lossless JPEG does not allow flexibility of the code stream, to overcome this JPEG 2000[1-2] has been proposed. This technique performs lossless compression based on an integer wavelet filter called biorthogonal 3/5. JPEG 2000‟ s lossless mode runs really slow and often has less compression ratios on artificial and compound images. To overcome this drawback JPEG-LS [6] has been proposed. This is a simple and efficient baseline algorithm containing two distinct stages called modeling and encoding. This technique is a standard evolved after successive refinements as shown in articles [3], [4], and [5]. JPEG-LS algorithm is more scalable than JPEG and JPEG 2000.

II. LOSSLESS IMAGE COMPRESSION MODEL

Many image compression algorithms use some form of transform coding. Figure 5 shows a block diagram of encoder and decoder using transform coding. The first step is to obtain a mathematical transformation to the image pixels in order to reduce the correlation between the pixels. The result of the transform is known as the transform coefficients. After this step, in lossy compression, an explicit quantizer may be used, or an implicit quantizer such as the truncation of the bit stream may be used. The source of the data loss in image compression is the quantizer. Thus, in the lossless compression case, the quantizer is not used. The third step is coefficient coding, which means that the transform coefficients are reorganized in order to exploit properties of the transform coefficients and obtain

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new symbols to be encoded at the fourth step. For example, the transform coefficients can be considered as a collection of quad-trees or zero-trees [8] [9] and or treated in a bit plane fashion, so as to provide

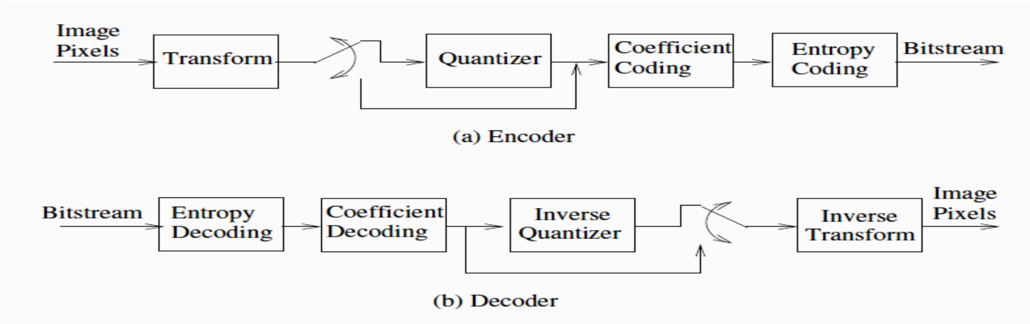

Fig. 1: Block Diagram of an Encoder and Decoder using Transform Coding

Scalability to the compressed bit stream. The symbols from the coefficient coding are losslessly compressed at the entropy coding step. Entropy coding can be any method capable of compressing a sequence of symbols, such as Huffman coding [10], arithmetic coding [11] and Golomb coding [12].

III. LOSSLESS COMPRESSION CODING TECHNIQUES

In this section different coding techniques used to achieve lossless compression are discussed. The primary encoding algorithms used to produce bit sequences are entropy coding techniques of which the most efficient are Huffman coding (also used by DEFLATE) and arithmetic coding. We also go over lossless predictive coding technique.

A. Entropy Coding

Entropy measures the amount of information present in the data or the degree of randomness of the data. After the data has been quantized into a finite set of values it can be encoded using an entropy coder to achieve additional compression using probabilities of occurrence of data. This technique reduces the statistical redundancy. The entropy coder encodes the given set of symbols with the minimum number of bits required to represent them. It is a variable length coding which means that it assigns different number of bits to different gray levels. If the probability of occurrence is more, then fewer bits/sample will be assigned.

ENTROPY (H): Suppose we have M input levels or symbols (S1, S2…SM) with their probabilities (P1, P2…., PM)

$$H = -\sum_{K=1}^{M} P_k \log_2 P_k = \sum_{k=1}^{M} P_k \log_2 (1/P_k) .$$

In the **least random** case it takes only one value where **$H = 0$**

Most random case: **$H = \log_2 M$** .

The average number of bits per pixel needed with Huffman coding is given by

$$R = \sum_{K=1}^{M} P_k N_K$$

Where P_k represent the probabilities of the symbols and N_k represent the number of bits per the code generated. Coding efficiency (η) can also be calculated using H and R generated earlier

$$\eta = \frac{H}{R} * 100$$

B. Huffman Coding

Huffman coding is an entropy coding algorithm which is used in lossless compression. In this technique the two smallest probabilities are combined or added to form a new set of probabilities. This uses a variable length code table which is based on the estimated probability of occurrence for each possible value of the source symbol. This is developed by David. A. Huffman. In Huffman coding each symbol is represented in a specific method which expresses the most common characters with fewer strings than used for any other character. It is not optimal when the symbol-by-symbol restriction is dropped, or when the probability mass functions are unknown, not identically distributed, or not independent.The basic technique involves creating a binary tree of nodes which can be finally stored as an array. This size depends on the number of symbols which have given probabilities. Now the lowest two probabilities will be added and one probability will be represented by „0‟ and the other probability which is added will be assigned a „1. This process is repeated until all the additions are completed leaving a sum of one. The simplest construction algorithm uses a priority queue where the node with lowest probability is given highest priority. The performance of the method is calculated using entropy.

IV. INTEGER WAVELET TRANSFORM

The wavelet transform generally produces floating-point coefficients. Although the original pixels can be reconstructed by perfect reconstruction filters without any loss in principle, the use of finite-precision arithmetic and quantization prevents perfect reconstruction. The reversible IWT (Integer Wavelet Transform), which maps integer pixels to integer coefficients and can reconstruct the original pixels without any loss, can be used for lossless compression [13] [14] [15] [16]. One approach used to construct the IWT is the use of the lifting scheme (LS) described by Calderbank et al. The IWT construction using lifting is done in the spatial domain, contrary to the frequency domain implementation of a traditional wavelet transform [16] [17]. Since many of the wavelet transform coefficients for a typical image tend to be very small or zero, these coefficients can be easily coded. Thus, wavelet transforms are a useful tool for image compression. The main advantage of wavelet transforms over other more traditional decomposition methods (like the DFT and DCT) is that the basis functions associated with a wavelet decomposition typically have both long and short support. The basis functions with long support are effective for representing slow variations in an image while the basis functions with short support can efficiently represent sharp transitions (i.e., edges).

V. LIFTING SCHEME

The simplest lifting scheme is the lazy wavelet transform, where the input signal is first split into *even* and *odd* indexed samples.

$$(odd_{j-1} , even_{j-1}) = Split(s_j)$$

The samples are correlated, so it is possible to predict odd samples from even samples which in the case of Haar transform are even values themselves. The difference between the actual odd samples and the prediction becomes the wavelet coefficients. The operation of obtaining the differences from the prediction is called the lifting step. They become the scaling coefficients which will be passed on to the next stage of transform. This is the second lifting step.

$$d_{j-1} = odd_{j-1} - P(even_{j-1})$$

$$s_{j-1} = even_{j-1} + U(d_{j-1})$$

Finally the odd elements are replaced by the difference and the even elements by the averages. The computations in the lifting scheme are done in place which saves lot of memory and computation time. The lifting scheme provides integer coefficients and so it is exactly reversible. The total number of coefficients before and after the transform remains the same.

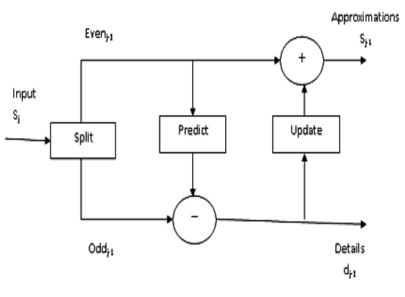

Fig. 2: Forward Lifting Scheme

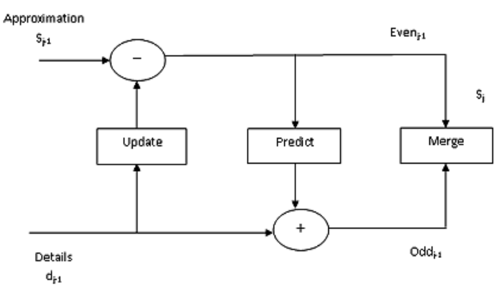

Fig. 3: Inverse Lifting Scheme

The inverse transform gets back the original signal by exactly reversing the operations of the forward transform with a merge operation in place of a split operation. The number of samples in the input signal must be a power of two, and these samples are reduced by half in each succeeding step until the last step which produces one sample.

$$Even_{j-1} = s_{j-1} - U(d_{j-1})$$

$$Odd_{j-1} = d_{j-1} + P(Even_{j-1})$$

Finally

$$s_j = Merge(Even_{j-1} , Odd_{j-1})$$

The Haar wavelet transform uses predict and update operations of order one. Using different predict and update operations of higher order, many other wavelet transforms can be built using the lifting scheme.

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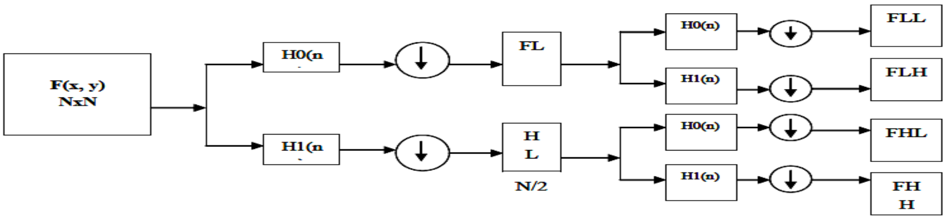
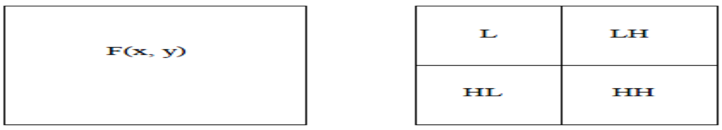


Fig. 4: Steps for Decomposition Using Lifting

Basic steps involved in the decomposition are illustrated in Fig.4[18]. Firstly the image/signal is sent through a low pass and band pass filter simultaneously (predict and update in case of lifting) and down sampled by a factor of 2. The process is repeated and the final four outputs are combined to from the transformed image as shown in Fig.3.8.



Original Image   Transformed Image

Fig. 5: Input and Outputs of Lifting Scheme

The transformed image shows different sub bands of which the first sub band is called LL which represents the low resolution version of the image, the second sub band is called LH which represents the horizontal fluctuations, the third band is called the HL which represents the vertical fluctuations, and the fourth sub band is called the HH which represents the diagonal fluctuations.

VI. Introduction To Predictive Coding

The prediction technique computes the weighted differences between neighboring pixel values to estimate the predicted pixel value. The prediction error is decomposed by a one-level integer wavelet transform to improve the prediction. . The differences are taken between the original sample and the sample(s) before the original sample. Let f (n) be the original sample then the difference d (n) will be given by

$$d(n) = f(n) - f(n-1).$$

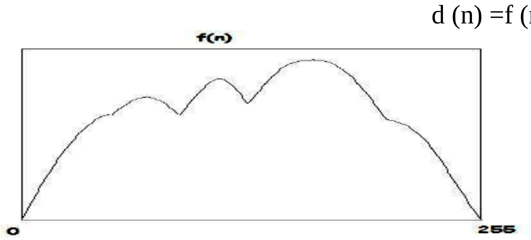


Fig. 6: Original Histogram

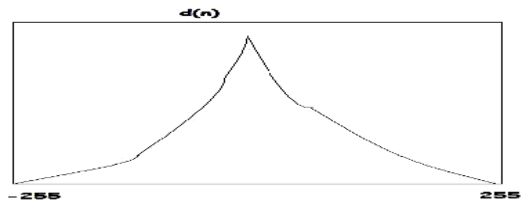


Fig. 7: Histogram of the difference

Fig.7 shows that it is easier to encode the difference rather than encoding the original sample because of less dynamic range.

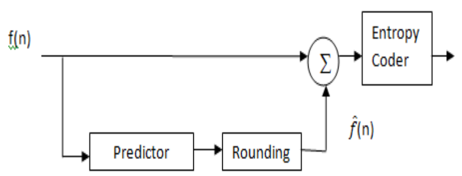


Fig. 8: Predictive Encoder

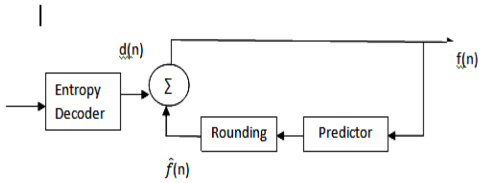


Fig. 9: Predictive Decoder

Generally, the second order predictor is used which is also called Finite Impulse Response (FIR) filter. The simplest predictor is the previous value, in this experiment the predicted value is sum of the previous two values with alpha and beta being the predictor coefficients.

$$\hat{f}(n) = <f(n-1)>$$

In the process of predictive coding input image is passed through a predictor where it is predicted with its two previous values.

$$\hat{f}(n) = \alpha * f(n-1) + \beta * f(n-2)$$

$\hat{f}(n)$ is the rounded output of the predictor, f(n-1) and f(n-2) are the previous values, α and β are the coefficients of the second order predictor ranging from 0 to 1. The output of the predictor is rounded and is subtracted from the original input. This difference is given by

$$d(n) = f(n) - \hat{f}(n)$$

Now this difference is given as an input to the decoder part of the predictive coding technique. In the decoding part the difference is added with the f^ (n) to give the original data

$$. f(n) = d(n) + \hat{f}(n)$$

VII. Implementation And Experimental Results

In this report the Integer Wavelet Transform (IWT) and the Predictive Coding Techniques are used to perform lossless image compression. The performance of the proposed techniques is calculated by finding the Entropy and scaled entropy of the compressed image. The performance is also measured using compression ratio which is given by the ratio of the bits in the original uncompressed data to the number of bits in the compressed data.

A. Procedure

The procedure of the implementation involves two methods of performing compression on the test images. In the first method the predictive coding technique is applied first followed by the integer wavelet transform. The second method involves reduction of the filter coefficients by a factor of 3/2 and performing predictive coding followed by integer wavelet transform. All these methods use Haar filter in the lifting scheme and the filter coefficients are given by

h1= [-1 9 9 1]/ (16);
h2= [0 0 1 1]/ (-4);

Where h1 are the prediction filter coefficients and h2 are the update filter coefficients in the lifting scheme.
The reduced filter coefficients are given by

h1= [-1 9 9 1]/ (16*1.5);
h2= [0 0 1 1]/ (-4*1.5);

The implementation of all the two methods for cameraman image is also shown in the results.

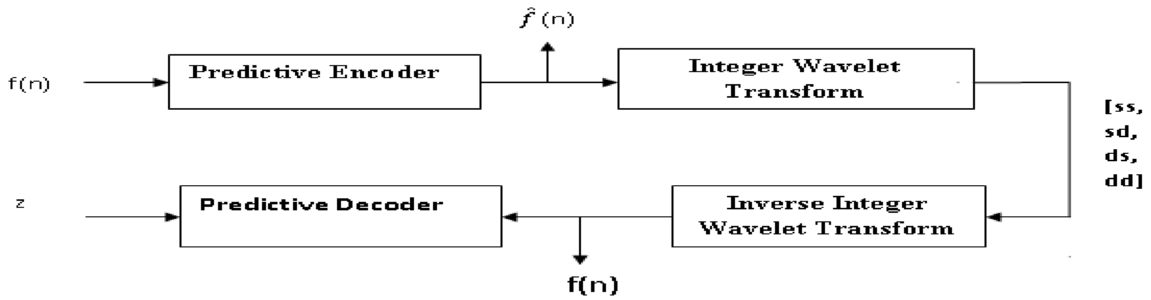


Fig. 10: Block Diagram for Predictive Coding Followed by IWT

In this method predictive coding is applied on image first, this converts the image into f^ (n). Now on this output integer wavelet transform is applied which divides the image into four sub bands ss, sd, ds, dd. The reconstruction process involves applying the inverse integer wavelet transform on the transformed image followed by applying predictive decoding on the output of the inverse transform F (n). The reconstructed image is represented by z.

IMAGE	PIXELS	NO. OF SUBBANDS	COMPRESSION RATIO
Lena	256x256	4	1.070
Barbara	256x256	4	4.058
Cameraman	256x256	4	1.040
Taj	500x500	4	2.85

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Pepper	256x256	4	8.361
Goldhill	256x256	4	6.435

Table 1: Compression Ratio of different test images

IMAGE	ORIGINAL ENTROPY	METHOD 1 SCALED ENTROPY	METHOD 2 SCALED ENTROPY
Lena	0.9878	0.4193	0.2825
Barbara	0.9989	0.6386	0.5712
Cameraman	0.9990	0.7216	0.7002
Taj	0.9862	0.7804	0.9785
Pepper	0.9903	0.5345	0.4404
Goldhill	0.9909	0.6478	0.5709

Table 2: Scaled entropy of different test images using method 1 and method

Algorithm	Compression Ratio			
	LENA 1 (512X512)	BARBARA (256x256)	LENA 2 (256X256)	MARS (256X256)
Proposed	8.39	7.42	6.63	2.25
JPEG (Existing)	1.81	1.41	1.66	1.61

Table 3: Comparison with the Previous Method

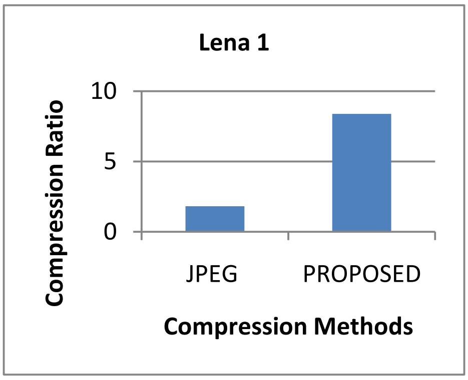

Fig. 11: Comparison bar graph of proposed method with JPEG for Lena 1

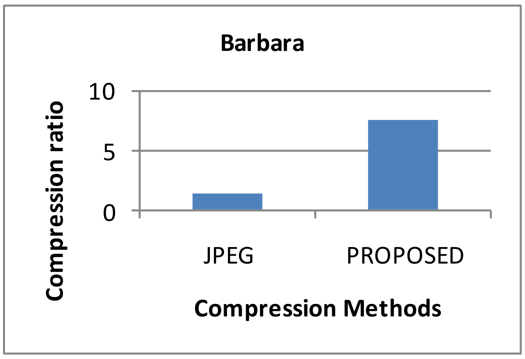

Fig. 12: Comparison bar graph of proposed method with JPEG for Barbara

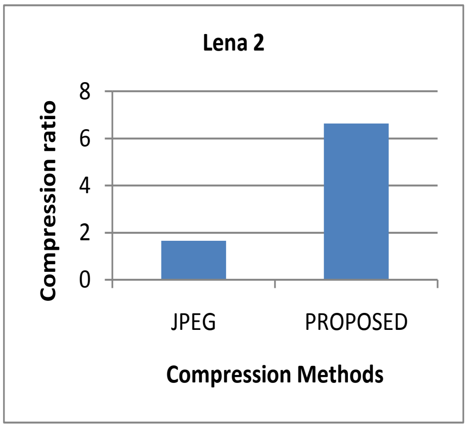

Fig. 13: Comparison bar graph of proposed method with JPEG for Lena 2

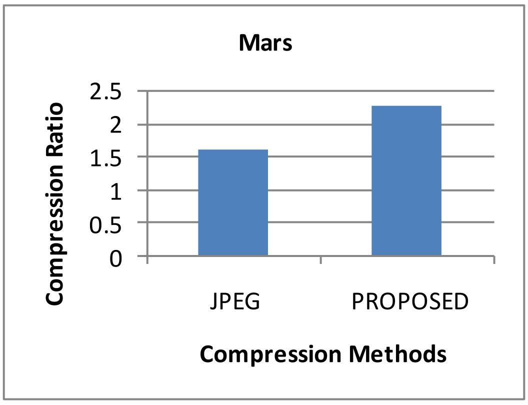

Fig. 14: Comparison bar graph of proposed method with JPEG for Mars

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B. Implementation using method 1

Fig 15: Original image of Taj mahal

Fig 16: Image of Taj after Predictive Encoding

Fig 17:Image obtained after Subband Coding

Fig 18:Image obtained after Inverse IWT

Fig 19:Image obtained after Predictive Decoding

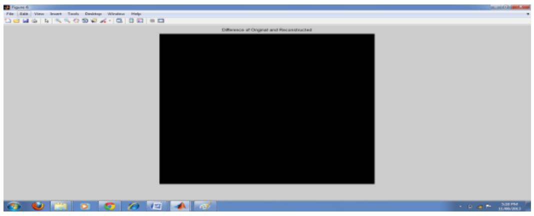

Fig 20: Difference of Original and Reconstructed Image

C. Implementation using method 2

Fig 21: Original image of Taj Mahal

Fig 22: Image of Taj after Predictive Encoding

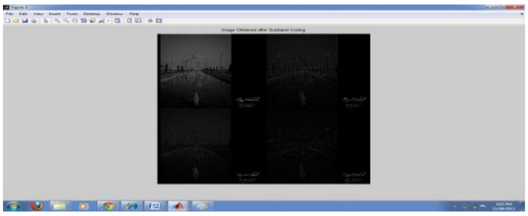

Fig 23: Image obtained after subband coding

Fig 24: Image obtained after Inverse IWT

Fig 25:Image obtained after Predictive Decoding

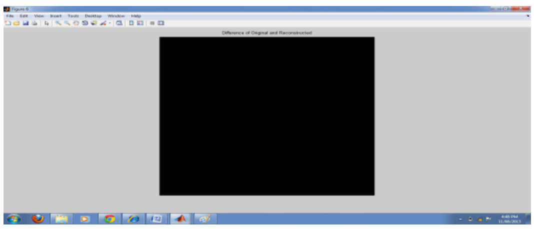

Fig 26: Difference of Original and Reconstructed

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SERIAL NO.	ALPHA	BETA	ORIGINAL ENTROPY	SCALED ENTROPY
1	0.1	0.1	0.9862	0.7144
2	0.1	0.2	0.9862	0.7300
3	0.3	0.3	0.9862	0.7804
4	0.5	0.5	0.9862	0.8826
5	0.7	0.7	0.9862	0.7694
6	0.9	0.7	0.9862	0.7481
7	0.01	0.1	0.9862	0.7035
8	0.1	0.01	0.9862	0.7026
9	0.01	0.01	0.9862	0.6920
10	0.9	0.9	0.9862	0.7347

Table 4: Scaled Entropy of Taj for different values of alpha and beta

SERIAL NO.	ALPHA	BETA	ORIGINAL ENTROPY	SCALED ENTROPY
1	0.1	0.1	0.9862	0.9578
2	0.1	0.2	0.9862	0.9622
3	0.3	0.3	0.9862	0.785
4	0.5	0.5	0.9862	0.8655
5	0.7	0.9862	0.9862	0.5320
6	0.9	0.7	0.9862	0.4911
7	0.01	0.1	0.9862	0.9550
8	0.1	0.01	0.9862	0.9542
9	0.01	0.01	0.9862	0.9517
10	0.9	0.9	0.9862	0.4640

Table 5: Scaled Entropy for different values of alpha and beta when filter coefficients are reduced by 2/3

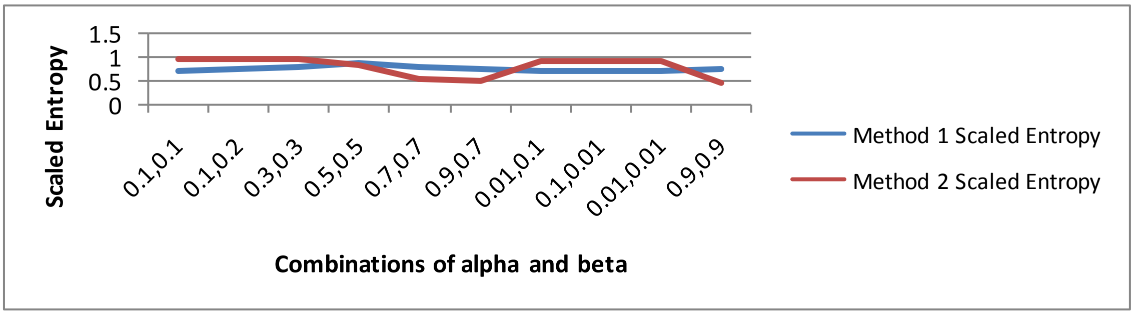

Fig 27: Comparison of Entropy's of method 1 & method 2 for different alpha & beta

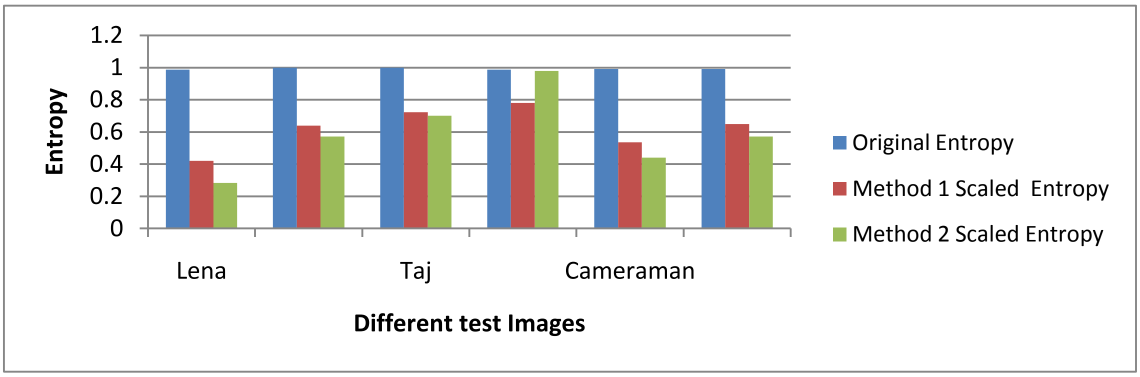

Fig 28: Bar graph showing Scaled Entropy of different Images

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VIII. CONCLUSION

In this paper, a lossless image compression method is presented first using predictive coding and then Integer Wavelet Transform for different test images. The compression ratio is calculated for different test images such as Lena1(512x512)[20],Barbara(256x256)[20],Taj(500x500)[19],Cameraman(256x256)[20],Pepper(256x256)[20] , Goldhill(256x256)[20], Lena2(256x256)[20] , Mars (256x256)[20] .This compression method offers higher compression ratio than previous compression method such as JPEG for test images such as Lena 1, Barbara, Lena 2, and Mars and compression bar graphs are also drawn for these test images to show that our method is efficient than previous method . The high compression efficiency is seen to be achieved by not only a combination of PREDICTIVE CODING and IWT, but also by optimisation in the design of the predictor and the choice of the transform. Here 4 levels of IWT is used to show that performance is purely lossless. After that scaled entropy of different test images are calculated for different test images using two method .The first methods employs predictive coding technique on the image followed by the integer wavelet transform giving a transformed output, which is then passed through the reverse techniques to get back the original image. The second method performed on the image involve reduction of the Haar filter coefficients by a factor of 3/2 and both methods are implemented on all the images. Entropy and scaled entropy are used to calculate the performance of the system, which calculates the number of bits per pixel. A lower entropy and scaled entropy indicate higher performance of the system. The analysis of experimental results has given some conclusions .Predictor coefficients alpha and beta value can lie between 0 and 1 and its choice is critical, so different combinations of these coefficients are tested. The best combination in methods 1 and 2 are (0.01, 0.01) & (0.9, 0.9) has been highlighted in the table 4 & 5 respectively. Comparison graph (Fig 27) for different values of alpha and beta and bar graph (Fig. 28) showing scaled entropy for different test images are also drawn. Among both, the second methods of performing predictive coding followed by integer wavelet transform using the reduced filter coefficients gave a better compression. This process reduced the entropy of the original image by almost 40%.

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