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Lossy Image Compression Using Wavelet Transform, Polynomial Prediction And Block Truncation Coding

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Abstract: *In this paper, a lossy image compression is introduced, it based on utilizing three techniques of wavelet, polynomial prediction and block truncation coding, in which each technique exploited in away according to redundancy presents. The test results shown are promising performance in terms of higher compression performance achieved with lower noticeable error or degradation.*

I. Introduction

Image compression of lossy based have become an increasingly intensive research area, due to importance to our daily visual media applications, including TV, video film, the internet etc, which basically based on losing some unrecognized or unwanted information, and managing non-noticeable distortion quality changes is traded off against high compression ratios. The extremely useful and well known lossy international standards, JPEG and JPEG 2000, based on transform coding that utilizes discrete cosine transform (DCT) and discrete wavelet transform (DWT), respectively, characterized by highly compression efficiency without visual degradation – that is to say that the result is still quite visually pleasing [1-4]. On the other hand, various lossy techniques available still under development such as vector quantizer, block truncation and fractal, based on exploiting the spatial coding efficiently. Reviews of various lossy techniques can be found in [5-9]. In this paper a hybrid efficient image compression technique is introduced based on exploited the transform coding of wavelet transform and spatial coding of polynomial prediction coding and block truncation. The rest of the paper is organized as follows, section 2 contains comprehensive clarification of the proposed system; the results of the proposed system is given in section 3.

II. The Proposed System

The implementation of the hybrid lossy image compression system of multiresolution wavelet based along with polynomial and block truncation is explained in the following steps, the layout of the proposed system is illustrated in Figure 1:

Step 1: Load the original uncompressed gray image I of size $N\times N$.

Step 2: Apply two successive wavelet transform, starts by decomposing the image I into first layer (layer$_1$) of four quadrants (LL_1, LH_1, HL_1 and HH_1) each of size ($N/2\times N/2$), then subsequently decompose the first layer detail sub bands of LH_1 and HL_1 into second layers each of four quadrants of size ($N/4\times N/4$). The techniques simply based on utilizing the wavelet transform more than once, by using the details subband of the preceding layer. The resultant, quadrants images with various resolution and details obtained (i.e., LL_1 and HH_1 of layer$_1$, while LL_2, LH_2, HL_2 and HH_2 of layer$_2$ of LH_1 and HL_1), each utilized the redundancy embedded in different way to improve the compression performance.

Step 3: For the approximation subband of the first layer (LL_1) that resembles the original image I of size ($N/2\times N/2$), the polynomial prediction model of linear base adopted such as:

1- Partition the (LL_1) into non-overlapping blocks of squared fixed sized regions of $n\times n$, and compute the coefficients according to the equations (1,2& 3)[10-11].

$$a_0 = \frac{1}{n\times n}\sum_{i=0}^{n-1}\sum_{j=0}^{n-1} LL_1(i,j) \text{.............}(1)$$

$$a_1 = \frac{\sum_{i=0}^{n-1}\sum_{j=0}^{n-1} LL_1(i,j)\times(j-x_c)}{\sum_{i=0}^{n-1}\sum_{j=0}^{n-1}(j-x_c)^2} \text{.......}(2)$$

$$a_2 = \frac{\sum_{i=0}^{n-1}\sum_{j=0}^{n-1} LL_1(i,j)\times(i-y_c)}{\sum_{i=0}^{n-1}\sum_{j=0}^{n-1}(i-y_c)^2} \text{.......}(3)$$

Where LL_1 (i,j) is the first layer approximation sub-band of original image block of size ($n\times n$) and

$$xc = yc = \frac{n-1}{2} \text{........................}(4)$$

Each block of size $n\times n$ represented by three coefficients (a_0,a_1 & a_2) corresponds to the mean , ratio of the pixel to the distance from the center in x and y direction, respectively.

2-Quantize the coefficients using the scalar uniform quantizer. The coefficients quantized with different quantization steps according to its importance, where the a_0 quantized with higher quantization level to keep the image information that represented by mean perceived as much as possible, while the a_1 & a_2 quantized with the same less quantization step compared to a_0. The dequantized required to reconstruct the approximated coefficients, the quantizer/dequantizer as shown in equations 5-7.

$$a_0Q = round(\frac{a_0}{QS_{a0}}) \rightarrow a_0D = a_0Q \times QS_{a0} \text{........(5)}$$

$$a_1Q = round(\frac{a_1}{QS_{a_{coff}}}) \rightarrow a_1D = a_1Q \times QS_{a_{coff}} \text{..........(6)}$$

$$a_2Q = round(\frac{a_2}{QS_{a_{coff}}}) \rightarrow a_2D = a_2Q \times QS_{a_{coff}} \text{........(7)}$$

Where QS_{a0} quantization step of a_0 coefficient and $QS_{a_{coff}}$ quantization step of both a_1 & a_2 coefficients.

3-Create the predicted image value $\tilde{I}$ using the dequantized polynomial coefficients of each block representation:

$$\tilde{L}L_1 = a_0D + a_1D(j - x_c) + a_2D(i - y_c) \text{......................(8)}$$

The predicted image $\tilde{I}$ resemble the original image but with less accuracy due to the prediction principle.

4- Find the residual as the difference or error between the predicted and original one.

$$R(i, j) = LL_1(i, j) - \tilde{L}L_1(i, j) \text{........(9)}$$

5- Quantize the residual image, as discussed previously in (2) using the uniform scalar quantizer, such that:

$$RQ = round(\frac{R}{QS_R}) \text{....................(10)}$$

Where QS_R quantization step of residual image.

Step 4: For the detail subband of the first layer (HH_1) that represents the source of compression, in which it is not rich with data [12-13]. Block truncation coding of $n_s \times n_s$ (i.e., $n_s < n$) efficiently used, due to utilizing the one-bit quantizer (i.e., binary quantizer of two values of 0 and 1) scheme that basically based on the statistical moments; extensive details of the block truncation coding techniques can be found in [14-16].

Step 5: For the second layers sub bands, the system used the polynomial prediction techniques mentioned above used with the block truncation coding, such as:

1- For the approximation subband (LL_2) of LH_1 and HL_1, the polynomial prediction techniques adopted (step 3), but with small block size than layer1 that equal to $n_s \times n_s$ ($n_s < n$).

2- For the detail sub bands (LH_2, HL_2 & HH_2), the block truncation coding used (step 4) of block size equal to $n_s \times n_s$ ($n_s < n$).

Step 6: Encodes the compressed information, where for binary images resultant from the block truncation the run length coding utilized efficiently followed by LZW, whereas the quantized residual along with information composed of coefficients (a_0,a_1&a_2) and the moments (mean & standard deviation of block truncation) the LZW followed by Huffman coding exploited.

Step 7: To reconstruct the compressed (decoded) image, the reversed steps followed:

1- Decodes the encoded compressed information to reconstruct the values.

2- Dequantized the residual image, by multiplying by the residual quantization step.

$$RD = RQ \times QS_R \text{........(11)}$$

3- The approximation subband reconstructed using:

$$LL_1(i, j) = RD(i, j) + \tilde{L}L_1(i, j) \text{........(12)}$$

4- The second layer sub bands utilized subsequently to reconstruct the first layer then the first layer information used to reconstruct the image.

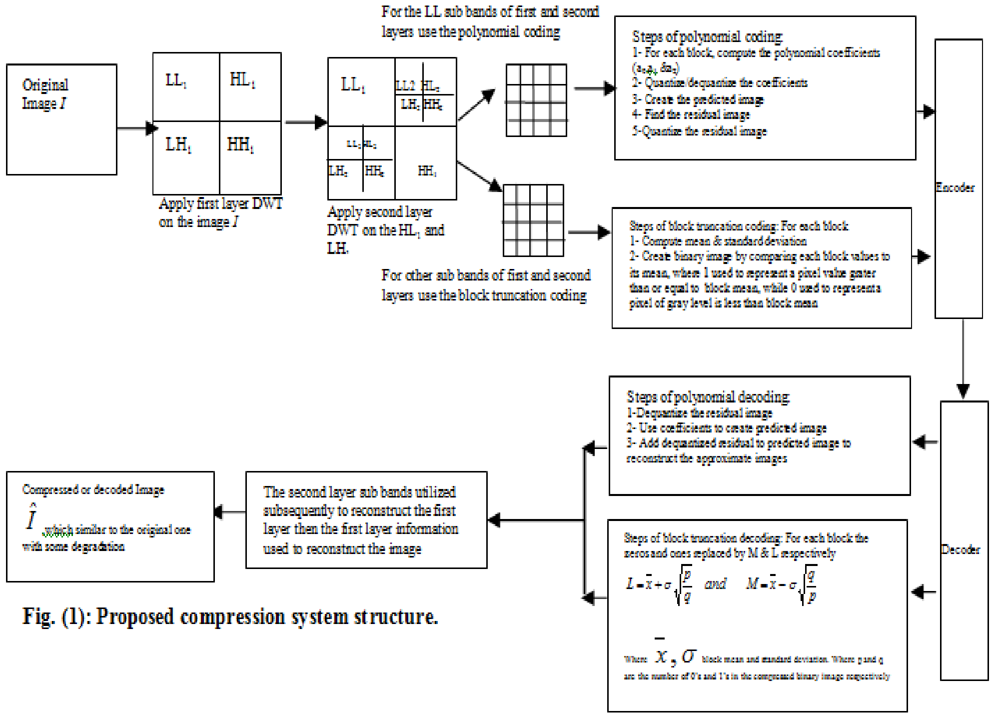

Fig. (1): Proposed compression system structure.

III. Experimental and Results

Basically for the lossy type the compression evaluation and image quality (i.e., fidelity criteria) used as tools to test the performance of the proposed system. The images used in the experiments are of different variation of details (see Figure 2 for an over view), all the images are square (256×256) gray images. The tests have been performed using Haar DWT of two layers, the block sizes adopted {4×4} and {2×2} for polynomial prediction and block truncation coding respectively, and different quantization steps are used to quantize the coefficients and residual images in first and second layers. The experimental result listed in Table (1), using the objective quantities measures, based on Compression Ratio and Normalized Root Mean Square Error (see equations 13 & 14 respectively). The examples of decompressed tested images are shown in Figure 3.

$$Comp.Ratio = \frac{Original\,Image\,Size}{Compressed\,Size} \quad \ldots\ldots..(13)$$

$$NRMSE(I,\hat{I}) = \sqrt{\frac{\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}[\hat{I}(x,y)-I(x,y)]^2}{\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}I(x,y)^2}} \quad \ldots\ldots\ldots\ldots \quad (14)$$

It is clear that the quantization step inversely affected both the compression ratio and quality, where as a small quantization step a high compression attainted with low quality, and as the quantization step gets bigger the compression decrease with high quality. Also the results illustrates that the quantization steps of approximation subband of layer1 (LL_1) that implicitly implies the coefficients and residual, higher than the approximation sub bands of layer2 of LH_1 and HL_1; in other words high quantization steps applied to layer$_1$ compared to layer$_2$ to preserve the information as much as possible. As well as, the higher quantization step of a_0 in both layers are utilized to keep the image details by preserving the mean efficiently. Certainly, the quantization step of residual images affected the appearance of the image (i.e., image quality), due to limitation in modelling efficiency; in other words the image information that can not be predicted accurately, actually found in the residual, which leads to noticeably small error of quantization coefficients compared to the quantization of the residual.

In general, the results vary according to the block size of two layer techniques. This means for polynomial coding and block truncation coding two block sizes adopted, also for the prediction techniques of approximation subband (LL_1) the block size of first layer bigger than the second layer.

Lastly, using the hybrid techniques of transformation based along with prediction and block truncation increase the system performance in terms of compression ratio & quality of images, where results vary according to image features or nature.

Fig.(2): Overview of the tested images (a) Lena image, (b) Rose image and (c) Paper image all images of size 256×256, gray scale images.

Fig. (3): Example of compressed tested images (a) Lena image, (b) Rose image and (c) Paper image

Table 1: The performance of the proposed system on the tested images using different quantization steps values for the residual images and the coefficients of $layer_1$ and $layer_2$

Test Images	LL_1 Quantization Steps of coefficients and Residual image				LL_2 of LH_1 Quantization Steps of coefficients and Residual image				LL_2 of HL_1 Quantization Steps of coefficients and Residual image				Block size {4×4} of polynomial approximation & Block size {2×2} of block truncation coding.	
	a_0	a_1	a_2	Res	a_0	a_1	a_2	Res	a_0	a_1	a_2	Res	Comp. Ratio	NRMSE
Lena	16	8	8	16	8	4	4	16	8	4	4	16	32.74	0.0504
	16	8	8	32	8	4	4	32	8	4	4	32	11.83	0.0372
	16	4	4	32	8	2	2	16	8	2	2	16	28.20	0.0419
	16	2	2	32	4	2	2	32	4	2	2	32	19.42	0.0417
	8	4	4	16	4	2	2	32	4	2	2	32	34.90	0.0607
	8	2	2	32	4	2	2	16	4	2	2	16	35.33	0.0434
Rose	16	8	8	16	8	4	4	16	8	4	4	16	31.92	0.0413
	16	8	8	32	8	4	4	32	8	4	4	32	11.36	0.0248
	16	4	4	32	8	2	2	16	8	2	2	16	22.18	0.0256
	16	2	2	32	4	2	2	32	4	2	2	32	22.66	0.0314
	8	4	4	16	4	2	2	32	4	2	2	32	35.78	0.0404
	8	2	2	32	4	2	2	16	4	2	2	16	39.28	0.0327
Paper	16	8	8	16	8	4	4	16	8	4	4	16	39.15	0.0390
	16	8	8	32	8	4	4	32	8	4	4	32	8.93	0.0262
	16	4	4	32	8	2	2	16	8	2	2	16	24.13	0.0315
	16	2	2	32	4	2	2	32	4	2	2	32	17.28	0.0312
	8	4	4	16	4	2	2	32	4	2	2	32	35.11	0.0462
	8	2	2	32	4	2	2	16	4	2	2	16	32.95	0.0321

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