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**RESEARCH ARTICLE**

# A Hybrid Lossy Image Compression based on Wavelet Transform, Polynomial Approximation Model, Bit Plane Slicing and Absolute Moment Block Truncation

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***Abstract*** **—** In this paper, a simple hybrid lossy image compression system is proposed, it is based on combining effective techniques, starts by wavelet transform that decompose the image signal followed by polynomial approximation model of linear based to compressed approximation image band. The error caused by applying polynonial approximation is coded using bit plane slice coding, on the other hand the absolute moment block truncation coding exploited to coded the detail sub bands. Then, the compressed information encoded using LZW, run length coding and Huffman coding techniques. The test results indicate that the proposed system can produce a balance between the compression performance and preserving the image quality.

## 1. Introduction

Image compression addresses the problem of reducing the amount of information required to represent a digital image [1-2]. Redundancy is a basic issue in digital image compression [3]. Image compression techniques are categorized into two main types depending on the redundancy removal way, namely Lossless and lossy [4]. Lossless image compression also called information preserving or error free techniques, as their name implicitly indicates, no loss of information, in which the data have been losslessly compressed, in other words, the original data can be reconstructed exactly from the compressed data based on the utilization of statistical redundancy alone (i.e. inter pixel redundancy and/or coding redundancy) with low compression rate, such as Huffman coding, Arithmetic coding, Run Length coding and Lempel-Ziv algorithm [5-8]. In lossy image compression that characterized by degrade image quality, in which the data have been lossly compressed, in other words, the original data can not be reconstructed exactly from the compressed data there is some degradation on image quality based on utilization of psycho-visual redundancy, either alone or combined with statistical redundancy with higher compression rate, such as Vector Quantization, Fractal, JPEG and Block Truncation coding [9-10]. Review on various lossless and lossy techniques can be found in [6-22].

Recently, a vast amount of work had been done to improve the performance of image compression techniques, with tools such as Wavelet that become used with an international standards JPEG2000 techniques, where image coder based on wavelet transform the image is decomposed into sub bands images prior to the encoding stage. In other words, wavelet transform tries to isolate different characteristic of a signal in way that collects the signal energy into few component, generally the implementation of wavelet lies in design of filters for sub-band coding [11, 12 -23]. Today, there is trend in the using of predictive coding, where many researchers have exploited to compress images, using a mathematical model that implicitly requires the form of the dependency (causal/ acausal), the order of the model (number of neighbours expolited) and the structure (1-D/2-D). Different modelling structures discussed in [7-18]. The predictive coding of polynomial based represents an alternative effective way to overcome traditional predictive coding restrictions mentioned above [19-11]. On the other hand, there is traditional simple fast techniques like bit-plane slicing image that sliced the image onto layers [20-21, 27] and block truncation coding (BTC) that ultized the first and second moments intelgently [13-15,19] with it is improved version that refereed as absolute moment block truncation coding(AMBTC) [16-17]. All the efficient standard techniques of hybrid base to increase the efficiency of performance, such as JPEG that exploited the discrete cosine transform (DCT) with predictive coding, review of hybrid techniques can be found in [24,25,26].

In this paper, a simple hybrid lossy techniques suggested for compressing gray images, based on utilizing the wavelet transform, polynomial representation of linear based along with the bit-plane slicing and AMBTC that exploted in an efficient way to improve the compression rate while preserving the image quality. The rest of the paper is organized as follows, section 2 contains comprehensive clarification of the proposed system; the result of the proposed system is given in section 3.

## 2. The Proposed System

In order to implement the proposed hybrid lossy image compression system, following steps are applied and Figure (1) clearly illustrated the system:

Step1: Load the input uncompressed image $I$ of size $N \times N$.

Step 2: Apply two-layered wavelet transform of multiresolution based, by decomposing the image $I$ into first layered wavelet of approximation ($LL_1$) and detail sub bands ($LH_1$,$HL_1$,$HH_1$), then subsequently the $LL_1$ decomposed into approximation subband ($LL_2$) and detail sub bands ($LH_2$,$HL_2$,$HH_2$)

Step 3: Perform the polynomial prediction of linear based for the second approximation subband ($LL_2$) using the steps below:

1- Partition the $LL_2$ sub band into non-overlapped blocks of fixed size $n \times n$, and performs the polynomial representation to the $LL_2$ band blocks according to equations (1,2,3) [12]:

$$a_0 = \frac{1}{n \times n} \sum_{i=0}^{n-1} \sum_{j=0}^{n-1} LL_2(i, j) \dots\dots\dots (1)$$

$$a_1 = \frac{\sum_{i=0}^{n-1} \sum_{j=0}^{n-1} LL_2(i, j) \times (j - x_c)}{\sum_{i=0}^{n-1} \sum_{j=0}^{n-1} (j - x_c)^2} \dots\dots (2)$$

$$a_2 = \frac{\sum_{i=0}^{n-1} \sum_{j=0}^{n-1} LL_2(i, j) \times (i - y_c)}{\sum_{i=0}^{n-1} \sum_{j=0}^{n-1} (i - y_c)^2} \dots\dots (3)$$

Where $LL_{2(i,j)}$ is the second approximation subband of the original image block of size ($n \times n$) and

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

2-Apply uniform scalar quantization to quantize the polynomial approximation coefficients, where each coefficient is quantized using different quantization step.

$$Q_{a_0} = round(\frac{a_0}{SQ_{a_0}}) \rightarrow D_{a_0} = Q_{a_0} \times SQ_{a_0} \dots (5)$$

$$Q_{a_1} = round(\frac{a_1}{SQ_{a_1}}) \rightarrow D_{a_1} = Q_{a_1} \times SQ_{a_1} \dots (6)$$

$$Q_{a_2} = round(\frac{a_2}{SQ_{a_2}}) \rightarrow D_{a_2} = Q_{a_2} \times SQ_{a_2} \dots (7)$$

 

Where $Q_{a_0}, Q_{a_1}, Q_{a_2}$ are the polynomial quantized values $SQ_{a_0}, SQ_{a_1}\ SQ_{a_2}$ are the quantization steps of the polynomial coefficients. The quantization step values affected the image quality and the compression ratio, and $D_{a_0}$, $D_{a_1}, D_{a_2}$ are polynomial dequantized values.

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

$$\tilde{I} = D_{a_0} + D_{a_1}(j - x_c) + D_{a_2}(i - y_c) \ldots (8)$$

4- Find the residual or prediction error as difference between the original *I* and the predicted one $\tilde{I}$ .

$$R(i, j) = LL_2(i, j) - \tilde{I}(i, j) \ldots\ldots\ldots\ldots (9)$$

5- Mapping the residual image to positive values (i.e., all negative values are mapped to be odd while the positive values will be even) as in equation (10) to avoid coding complexity due to existence of positive and negative values.

$$X_i = \begin{cases} 2X & if\ X_i \geq 0 \\ -2X_i - 1 & if\ X_i < 0 \end{cases} \ldots\ldots (10)$$

Where $X_i$ is the $i^{th}$ element residual value.

6- Apply the bit plane slicing techniques of the resultant mapped residual image, the technique basically based on slice the image onto layers, range from layer$_0$ corresponds to the Least Significant Layer (LSB) to layer$_7$ corresponds to the Most Significant Layer (MSB), only the high order layers from layer$_4$ to layer$_7$ are normally used, where the significant details preserved.

7- Perform the scalar uniform quantizer to quantize the slice residual mapped image of high order layers, in other words the sliced residual image from layer$_4$ to layer$_7$ quantized with different quantization step as in equations (11,12,13,14).

$$Qb_4 = round(\frac{b_4}{SQb_4}) \rightarrow Db_4 = Qb_4 \times SQb_4 \ldots (11)$$

$$Qb_5 = round(\frac{b_5}{SQb_5}) \rightarrow Db_5 = Qb_5 \times SQb_5 \ldots (12)$$

$$Qb_6 = round(\frac{b_6}{SQb_6}) \rightarrow Db_6 = Qb_6 \times SQb_6 \ldots (13)$$

$$Qb_7 = round(\frac{b_7}{SQb_7}) \rightarrow Db_7 = Qb_7 \times SQb_7 \ldots (14)$$

8- Create the quantized residual mapped image $\tilde{R}(i, j)$ from the dequantized high layers above.

Step 4: For the other detail sub-bands of the first and second layer $(LH_2, HL_2, HH_2, LH_1, HL_1\ and\ HH_1)$ the absolute moment block truncation coding (AMBTC) exploited, the following steps are applied for each subband:

1- Partition the subband into non-overlapped blocks of fixed size *m*×*m* where *m*<=*n* (use *2*×2 or 4×4).

2- Compute the mean of the partitioned block as equation (15).

$$\bar{x} = \frac{1}{m}\sum_{i=1}^{m} x_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Where $x_i$ represent the $i^{th}$ pixel value of the image block and *m* is the total number of pixels of block.

3- Pixels in the image block are then divided into two ranges of values. The upper range is those gray levels which are greater than the block average gray level $(\bar{x})$ and the remaining brought into the lower range. The mean of higher $XH$ and the lower range $XL$ are computed as equation (16 and 17).

$$x_H = \frac{1}{K}\sum_{x_i > x}^{m} x_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

$$x_L = \frac{1}{number\ of\ pixel\ in\ block - K}\sum_{x_i < x}^{m} x_i \ldots. (17)$$

Where *K* is the number of pixels whose gray level is greater than $\bar{x}$ .

4- Create the Binary image denoted by *B*, where the 1 corresponds to pixel value greater than or equal to $\bar{x}$ , otherwise the 0 used for pixel value smaller than to $\bar{x}$

$$B = \begin{cases} 1 & x_i \geq \bar{x} \\ 0 & x_i < \bar{x} \end{cases} \quad . \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

 

Step 5: Use encoder to code the compress information that composed of binary image if detail subbands layers and the coefficients and quantized residual image, the encoder use LZW, Run Length Coding, which is passed through Huffman Coding.

Step 6: The decoder or reconstruction unit, starts by reconstruction the compressed values then applying the inverse process that reconstruct or rebuild the detail sub bands by replacing the 1 with $XH$ and 0 with $XL$ as equation(19)

$$X = \begin{cases} X_L & B=0 \\ X_H & B=1 \end{cases} \quad \text{..............................(19)}$$

Also the coefficients with the residual utilized to reconstruct the approximation subband of the second layer as equation(20)

$$\hat{L}_{L2}(i,j) = \tilde{R}(i,j) + \tilde{I}(i,j) \text{......................(20)}$$

Lastly by applying the inverse wavelet transform to reconstruct the compressed image $\hat{I}$ as equation(21).

$$x_i = \begin{Bmatrix} x/2 & if\ x_i \geq 0 \\ (x+1)/2 & if\ x_i \prec 0 \end{Bmatrix} \text{..................(21)}$$

## 3. Experiments and Results

For testing the proposed system performance; four standard images are selected, the images of 256 gray levels(8 bits/pixel) of size 256×256( see Figure 2 for an overview). To evaluate the compression efficiency and image quality based on the compression ratio(CR), which is the ratio of the original image size to the compressed size, peak signal to noise ratio(PSNR) a large value implicitly means high image quality and close to the original image and vice versa with normalizes mean square error (NRMSE) where the range of the values between 0 and 1, if the value is close to zero refers to high image quality and vice versa as equations(22,23).

$$PSNR = 10.\log_{10}\left[\frac{(255)^2}{\frac{1}{N \times N}\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}\left[(\hat{I}(x,y) - I(x,y)\right]^2}\right] \text{..............(22)}$$

$$NRMSE(I,\hat{I}) = \sqrt{\frac{\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}[\hat{I}(x,y) - I(x,y)]^2}{\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} I(x,y)^2}} \text{.............(23)}$$

The result of the proposed system illustrates that the high compression rate is achieved because of utilization of effective multiresolution along with the efficient linear polynomial model of quantize three coefficients( $a_0, a_1, a_2$ ) and quantize the high order layer of residual image in which no need to extra information to be used. Implicitly meaning that the compression rate is directly affected by coefficients size compared to residual size, also the other detail subbands consumption of bytes compared to the linear polynomial part.

Certainly, the quality of the compressed image is improves the number of quantization levels of both the approximation representation coefficients and for the high order layer of residual image increase. The higher the quality required the larger the number of quantization level that must be used.

The result are shown in Table 1 lists the results for different values of the quantization step for the polynomial coefficients and for the high order layer of residual image, were selected to be between 16 to 64 levels for block size (2×2) and (4×4) to polynomial coefficients and absolute moment block truncation coding (AMBTC), also block size play an essential role in the process, the block size of (2×2) gives high image quality, while increase the block size to (4×4) the image quality become less( see Figure 3). Where compression ratio becomes higher and produce the trade-off between the quality desired and compression ratio. In other words , increase the block size gets bigger the higher compression ratio with higher error and vice versa. The quality of the compressed image is directly uninfluenced by using different quantization levels of the polynomial coefficients because of dominating the quantize high order layer of residual image, and also the other detail subbands are quantized based on two levels. Also the result demonstrates that the compression rates is directly affected by the size of polynomial approximation coefficients not the size of residual.

The tests indicate that the proposed system fast and simple to implement, high compression is attained because of utilization to quantize linear polynomial coefficients and quantize the high order layer of residual image and also quantize the other detail subband on using AMBTC of two levels quantization.

 

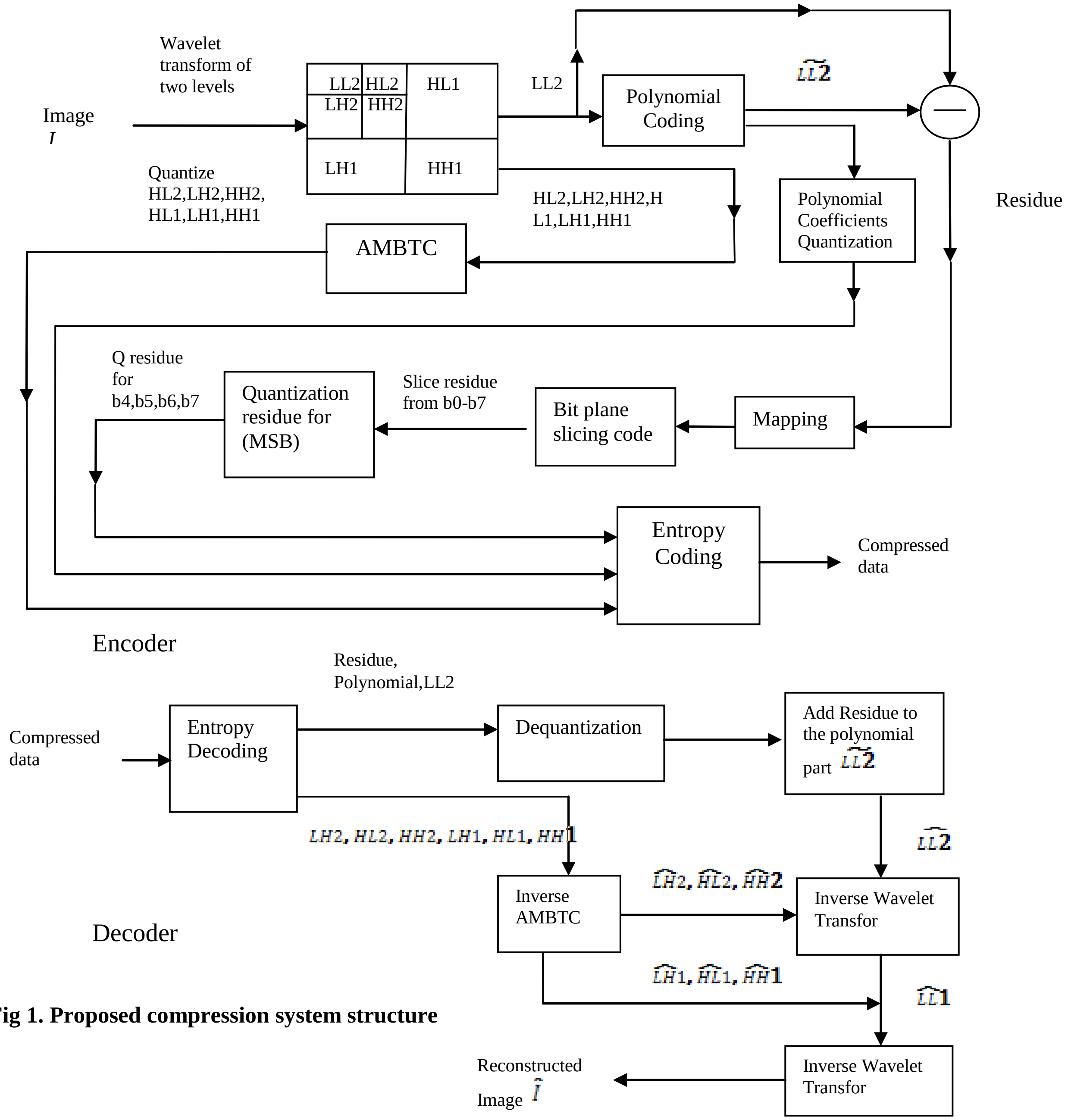


**Fig 1. Proposed compression system structure**

**Fig 2.Overview of the tested images (a)Lena image, (b)Pepper image, (c)Camera-man image and (d)Girl image, all images of size 256×256, gray scale images.**

**Table (1) lists the results for different values of the quantization step for the polynomial coefficients and for the high order layer of residual image, were selected to be between 16 to 64 level.**

| Test image | Orig. Size image | Coefficients Quantization levels & steps | | | Quantization Residual steps for Bit Plane slicing to Most Significant Bit(MSB), b4,b5,b6,b7 | | | | Block size {2*2} | | | | Block size {4*4} | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Qa0 | Qa1 | Qa2 | Rb4 | Rb5 | Rb6 | Rb7 | Comp . Size | NRMSE | PSNR | CR | Comp . Size | NRMSE | PSNR | CR |
| Lena | 65536 | 32 | 32 | 64 | 16 | 32 | 8 | 16 | 1438 | 0.0544 | 32.4227 | 45.5744 | 1342 | 0.0956 | 27.5191 | 48.8346 |
| | 65536 | 32 | 32 | 32 | 16 | 16 | 16 | 16 | 1424 | 0.0689 | 30.3620 | 46.0225 | 1332 | 0.0953 | 27.5451 | 49.2012 |
| | 65536 | 32 | 16 | 32 | 32 | 32 | 32 | 32 | 1410 | 0.0784 | 29.2389 | 46.4794 | 1328 | 0.0973 | 27.3645 | 49.3494 |
| | 65536 | 16 | 32 | 32 | 16 | 32 | 16 | 16 | 1396 | 0.0697 | 30.2705 | 46.9456 | 1330 | 0.0951 | 27.5676 | 49.2752 |
| | 65536 | 64 | 32 | 64 | 16 | 16 | 8 | 16 | 1444 | 0.0542 | 32.4472 | 45.3850 | 1340 | 0.0956 | 27.5212 | 48.9075 |
| | 65536 | 64 | 64 | 64 | 32 | 32 | 32 | 32 | 1450 | 0.0504 | 33.0848 | 45.1972 | 1342 | 0.0938 | 27.6874 | 48.8346 |
| | 65536 | 64 | 64 | 32 | 64 | 16 | 32 | 64 | 1442 | 0.0528 | 32.6687 | 45.4480 | 1338 | 0.0937 | 27.6959 | 48.9806 |
| Pepper | 65536 | 32 | 32 | 64 | 16 | 32 | 8 | 16 | 1428 | 0.0540 | 30.7567 | 45.8936 | 1328 | 0.0882 | 26.4941 | 49.3494 |
| | 65536 | 32 | 32 | 32 | 16 | 16 | 16 | 16 | 1426 | 0.0748 | 27.9272 | 45.9579 | 1326 | 0.0927 | 26.0639 | 49.4238 |
| | 65536 | 32 | 16 | 32 | 32 | 32 | 32 | 32 | 1408 | 0.0815 | 27.1775 | 46.5455 | 1316 | 0.0974 | 25.6310 | 49.7994 |
| | 65536 | 16 | 32 | 32 | 16 | 32 | 16 | 16 | 1404 | 0.0750 | 27.9023 | 46.6781 | 1322 | 0.0920 | 26.1282 | 49.5734 |
| | 65536 | 64 | 32 | 64 | 16 | 16 | 8 | 16 | 1446 | 0.0538 | 30.7865 | 45.3223 | 1326 | 0.0881 | 26.5070 | 49.4238 |
| | 65536 | 64 | 64 | 64 | 32 | 32 | 32 | 32 | 1454 | 0.0467 | 32.0164 | 45.0729 | 1328 | 0.0832 | 26.9977 | 49.3494 |
| | 65536 | 64 | 64 | 32 | 64 | 16 | 32 | 64 | 1448 | 0.0523 | 31.0335 | 45.2597 | 1324 | 0.0879 | 26.5244 | 49.4985 |
| Camera - man | 65536 | 32 | 32 | 64 | 16 | 32 | 8 | 16 | 1400 | 0.0497 | 31.6596 | 46.8114 | 1346 | 0.0891 | 26.5819 | 48.6895 |
| | 65536 | 32 | 32 | 32 | 16 | 16 | 16 | 16 | 1392 | 0.0621 | 29.7169 | 47.0805 | 1336 | 0.0903 | 26.4723 | 49.0539 |
| | 65536 | 32 | 16 | 32 | 32 | 32 | 32 | 32 | 1382 | 0.0724 | 28.3839 | 47.4211 | 1330 | 0.0916 | 26.3441 | 49.2752 |
| | 65536 | 16 | 32 | 32 | 16 | 32 | 16 | 16 | 1378 | 0.0625 | 29.6701 | 47.5588 | 1338 | 0.0906 | 26.4366 | 48.9806 |
| | 65536 | 64 | 32 | 64 | 16 | 16 | 8 | 16 | 1416 | 0.0496 | 31.6746 | 46.2825 | 1350 | 0.0892 | 26.5735 | 48.5452 |
| | 65536 | 64 | 64 | 64 | 32 | 32 | 32 | 32 | 1430 | 0.0452 | 32.4872 | 45.8294 | 1348 | 0.0892 | 26.5733 | 48.6172 |
| | 65536 | 64 | 64 | 32 | 64 | 16 | 32 | 64 | 1416 | 0.0476 | 32.0391 | 46.2825 | 1344 | 0.0904 | 26.4585 | 48.7619 |
| Girl | 65536 | 32 | 32 | 64 | 16 | 32 | 8 | 16 | 1416 | 0.0533 | 36.5775 | 46.2825 | 1338 | 0.0849 | 32.5345 | 48.9806 |
| | 65536 | 32 | 32 | 32 | 16 | 16 | 16 | 16 | 1408 | 0.0541 | 36.4487 | 46.5455 | 1340 | 0.0878 | 32.2407 | 48.9075 |
| | 65536 | 32 | 16 | 32 | 32 | 32 | 32 | 32 | 1396 | 0.0741 | 33.7125 | 46.9456 | 1328 | 0.0876 | 32.2617 | 49.3494 |
| | 65536 | 16 | 32 | 32 | 16 | 32 | 16 | 16 | 1394 | 0.0549 | 36.3135 | 47.0129 | 1328 | 0.0880 | 32.2236 | 49.3494 |
| | 65536 | 64 | 32 | 64 | 16 | 16 | 8 | 16 | 1436 | 0.0534 | 36.5563 | 45.6379 | 1344 | 0.0849 | 32.5352 | 48.7619 |
| | 65536 | 64 | 64 | 64 | 32 | 32 | 32 | 32 | 1442 | 0.0467 | 37.7263 | 45.4480 | 1352 | 0.0847 | 32.5535 | 48.4734 |
| | 65536 | 64 | 64 | 32 | 64 | 16 | 32 | 64 | 1440 | 0.0469 | 37.6944 | 45.5111 | 1348 | 0.0869 | 32.3330 | 48.6172 |

Same block size {2×2} of polynomial & AMBTC
CR=45.1972
NRMSE=0.0504
PSNR=33.0848

a

Same block size {4×4} of polynomial & AMBTC
CR=48.8346
NRMSE=0.0938
PSNR=27.6874

 

Same block size {2×2} of polynomial & AMBTC
CR=45.0729
NRMSE=0.0467
PSNR=32.0164

b

Same block size {4×4} of polynomial & AMBTC
CR=49.3494
NRMSE=0.0832
PSNR=26.9977

Same block size {2×2} of polynomial & AMBTC
CR=45.8294
NRMSE=0.0452
PSNR=32.4872

c

Same block size {4×4} of polynomial & AMBTC
CR=48.6172
NRMSE=0.0892
PSNR=26.5733

Same block size {2×2} of polynomial & AMBTC
CR=45.4480
NRMSE=0.0467
PSNR=37.7263

d

Same block size {4×4} of polynomial & AMBTC
CR=48.4734
NRMSE=0.0847
PSNR=32.5535

**Fig 3. Compressed test images with different block size and different quality (a) Lena image, (b)Pepper image,(c) Camera-man image and (d) Girl image respectively.**

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