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Image Compression based on Adaptive Polynomial Coding of Hard & Soft Thresholding

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Abstract

In this paper, an adaptive polynomial compression technique is introduced of hard and soft thresholding of transformed residual image that efficiently exploited both the spatial and frequency domains, where the technique starts by applying the polynomial coding in the spatial domain and then followed by the frequency domain of discrete wavelet transform (DWT) that utilized to decompose the residual image of hard and soft thresholding base. The results showed the improvement of adaptive techniques compared to the traditional polynomial coding technique.

Keywords: Image compression, polynomial coding and hard and soft thresholding.

طريقة مطورة لضغط الصور باستخدام متعدد الحدود للعتبة القاسية والسهلة

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الخلاصة:

في هذا البحث، سنقدم تقنية ضغط متعدد الحدود المطورة للعتبة القاسية والسهلة لتحويل الجزء الباقي من الصورة التي تستغل كلا من المجالات المكانية والمتكررة بكفاءة، حيث التقنية تبدأ بتطبيق متعدد الحدود في المجال المكاني ومتبوعة بالمجال المتكرر باستخدام التحويل المويجي المتقطع التي تستخدم لضغط الجزء الباقي بالعتبة القاسية والسهلة. اظهرت النتائج التحسن في التقنيات المطورة بالمقارنه مع تقنية متعدد الحدود التقليدية.

Introduction

Image compression techniques are categorized into two main types depending on the redundancy removal way, namely lossless and lossy. Lossless image compression of no information loss, also called information preserving or error free techniques where the reconstructed identical to the original data, that utilized the statistical redundancy with low compression ratio, such as Huffman coding, Arithmetic coding, Run Length coding and Lempel-Ziv algorithm. While in lossy image compression some information are lost, where the original data cannot be reconstructed exactly from the compressed data. The degradation of image quality based on utilization of psycho-visual redundancy, either alone or combined with statistical redundancy with higher compression ratio, such as Vector Quantization, Fractal, JPEG and Block Truncation coding [1-3].

The traditional polynomial coding is characterized by simplicity, that is basically based on computing the coefficients that implicitly exploited to create the predicted image, then finding the residual (prediction error) between the original and the created predicted image, but with low compression ratio achieved due to utilization of spatial domain alone [4-6].

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In this paper, the adaptive polynomial coding is incorporate the transform coding of residual part using the hard and soft thresholding techniques to improve the performance of the traditional polynomial coding. The adaptive techniques discussed in section 2 and the results are given in section3.

The Adaptive Polynomial Coding

This paper is concerned with removing the psychovisual redundancy of residual part of wavelet transformed domain based, by utilizing the hard and soft thresholding techniques. The steps bellow explain the proposed system and depicted with Figure-1.

Step 1: Load the input uncompressed gray image *I* of *BMP* format of square size *N*×*N*.

Step 2: Partition the image (*I*) into non overlapped blocks of fixed size *n*×*n*, such as (4×4) or (8×8) then compute the polynomial coefficients according to equations (1-3).

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

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

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

Where a_0 coefficient corresponds to the mean (average) of block of size (*n*×*n*) of input image *I*. The a_1 and a_2 coefficients represent the ratio of sum pixel multiplied by the distance from the center to the squared distance in *i* and *j* coordinates respectively, and the (j-x_c) and (i-y_c) corresponds to measure the distance of pixel coordinates to the block center (x_c, y_c) [4].

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

Step 3: Apply uniform scalar quantization/dequantization of the computed polynomial approximation coefficients, where each coefficient is quantized using different quantization step.

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

$$a_1Q = round\left(\frac{a_1}{QS_{a1}}\right) \rightarrow a_1D = a_1Q \times QS_{a1} \quad \text{..........(6)}$$

$$a_2Q = round\left(\frac{a_2}{QS_{a2}}\right) \rightarrow a_2D = a_2Q \times QS_{a2} \quad \text{........(7)}$$

Where a_0Q, a_1Q, a_2Q are the polynomial quantized values, $QS_{a0}, QS_{a1}, QS_{a2}$ are the quantization steps of the polynomial coefficients, and a_0D, a_1D, a_2D are polynomial dequantized values.

Step 4: Create the predicted image value $\tilde{I}$ using the dequantized polynomial coefficients for each encoded block representation:

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

Step 5: Find the residual or prediction error as the difference between the original *I* and the predicted one $\tilde{I}$.

$$\mathrm{Res}(i, j) = I(i, j) - \tilde{I}(i, j) \quad \text{.....................................(9)}$$

Step 6: Use the wavelet transform of residual image resultant from the step above, then each quadrants quantized differently, where for the approximation subband (i.e., *LowLow*) the scalar uniform quantizer /dequantizer adopted as in equation (10), while for the detail's sub bands (i.e., *LowHigh, HighLow* and *HighHigh*) implies the utilization of either hard thresholding (see equations 11- 13) or soft thresholding (see equations 14-16). For more detail about hard and soft thresholding see [7].

$$\mathrm{Res}_{LowLow}Q = round\left(\frac{\mathrm{Res}_{LowLow}}{QS_{\mathrm{Res}_{LowLow}}}\right) \rightarrow \mathrm{Res}_{LowLow}D = \mathrm{Res}_{LowLow}Q \times QS_{\mathrm{Res}_{LowLow}} \quad (10)$$

$$\mathrm{Re}\,s_{LowHigh}Q = \begin{cases} \mathrm{Re}\,s_{LowHigh} if \left|\mathrm{Re}\,s_{LowHigh}\right\rangle . ThresoldLowHigh \\ 0 else \end{cases} \quad (11)$$

$$\mathrm{Re}\,s_{HighLow}Q = \begin{cases} \mathrm{Re}\,s_{HighLow} if \left|\mathrm{Re}\,s_{HighLow}\right\rangle . ThresoldHighLow' \\ 0 else \end{cases} \quad (12)$$

$$\mathrm{Re}\,s_{HighHigh}Q = \begin{cases} \mathrm{Re}\,s_{HighHigh} if \left|\mathrm{Re}\,s_{HighHigh}\right\rangle . ThresoldHighHigh \\ 0 else \end{cases} \quad (13)$$

$$\mathrm{Re}\,s_{LowHigh}Q = \begin{cases} Sign(\mathrm{Re}\,s_{LowHigh})(\left|\mathrm{Re}\,s_{LowHigh}\right| - ThresoldLowHigh if \left|\mathrm{Re}\,s_{LowHigh}\right\rangle . ThresoldLowHigh. \\ 0 else \end{cases} \quad (14)$$

$$\mathrm{Re}\,s_{HighLow}Q = \begin{cases} Sign(\mathrm{Re}\,s_{High}Low)(\left|\mathrm{Re}\,s_{HighLow}\right| - ThresoldLHighLow if \left|\mathrm{Re}\,s_{HighLow}\right\rangle . ThresoldHighLow \\ 0 else \end{cases} \quad (15)$$

$$\mathrm{Re}\,s_{HighHigh}Q = \begin{cases} Sign(\mathrm{Re}\,s_{HighHigh})(\left|\mathrm{Re}\,s_{HighHigh}\right| - ThresoldHighHigh if \left|\mathrm{Re}\,s_{HighHigh}\right\rangle . ThresoldHighHigh. \\ 0 else \end{cases} \quad (16)$$

Step 7: Encode the compressed information of quantized coefficients and quantized quadrants residual using the simple Huffman coding technique.

Step 8: Reconstruct the decoded image $\hat{I}$ using the decoded information (i.e., Huffman decoding), firstly by applying the inverse wavelet transform of residual image, secondly build up the predicted image as in equation (8) and finally adds them such that:

$$\hat{I}(i,j) = \tilde{I}(i,j) + \mathrm{Re}\,sD(i,j) \quad (17)$$

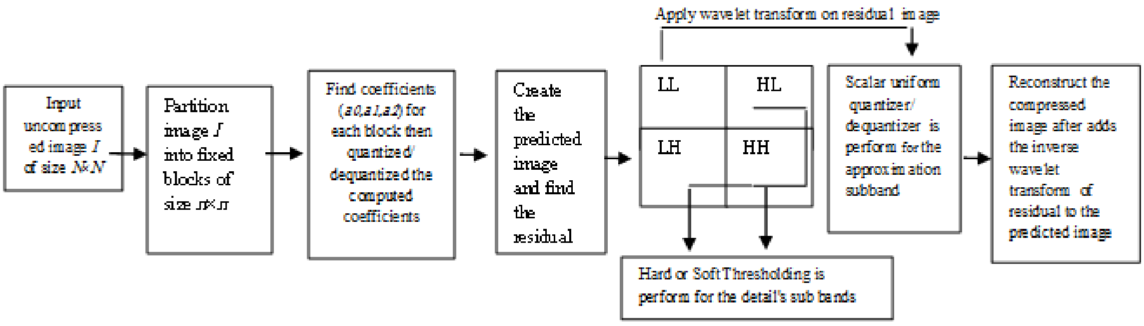

Figure 1- The proposed system structure.

Results and Discussion

For testing the proposed system performance; several of standard images used (see Figure 2), where all the images of 256 gray levels (8bits/pixel) of size 256×256, also the block sizes of (*4*×*4*) is adopted.

The compression ratio adopted, which is the ratio of the original image size to the compressed size along with the Peak -Signal-to Noise- Ratio (*PSNR*) between the original image *I* and the decoded image $\hat{I}$ was utilized as a fidelity or degradation measure as in equations (18 and19).

$$PSNR(dB) = 10 \log_{10}\left[\frac{(\max imumgray\ \ scale\ \ of\ \ image)^2}{MSE}\right] \quad (18)$$

$$MSE = \frac{1}{N \times N} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} [\hat{I}(x,y) - I(x,y)]^2 \quad (19)$$

a b c d

Figure 2- Overview of the tested images (a) Lena image, (b) Woman image, (c) Baboon image and (d) Pepper image, all images of size 256×256 scale images.

The results shown in Table - 1 illustrate the comparison between the traditional polynomial coding and the adaptive one of hard and soft thresholding techniques. Also, Figure-3 a-f illustrated the compressed tested images using 1,2,2 quantization steps of coefficients and the quantization step of residual image of both traditional and hard/soft thresholding was selected to be between 5 and 60.

The results show that the adaptive polynomial technique of both hard and soft thresholding is better performance in terms of the compression ratio (*CR*) than the traditional polynomial technique, due to the efficiently exploiting the residual image of the wavelet transform. In other words, the adaptive techniques here effectively work to use the transform coding of Haar base to exploit the spatial redundancy of residual image (prediction error). Also the results indicate that the higher image quality achieved of soft thresholding where the residual sign preserved. Therefore, the technique affected by keeping or not the residual sign image values of soft and hard thresholding techniques respectively. Lastly, the results showed the effect of the quantization step of residual image (i.e., traditional polynomial coding) and the approximation subband (i.e., *LowLow* of adaptive polynomial coding) along with various image details or characteristics

Table - 1 Comparison performance between traditional and adaptive polynomial coding techniques for tested images.

Tested Image	Block Size of 4x4 and Quantization Coefficients of 1,2,2								
	Traditional Polynomial Coding			Adaptive Polynomial Coding with details sub bands of 20,20,40					
				Hard Thresholding			Soft Thresholding		
	Quantization Residual	CR	PSNR	Quantization LL subband	CR	PSNR	Quantization LL subband	CR	PSNR
Lena	5	3.3227	45.0201	2	5.1312	29.9972	2	4.9201	33.3726
	20	4.2413	34.9135	10	6.3776	29.9642	10	6.0547	33.3010
	40	4.4329	31.1426	60	7.1034	29.5203	60	6.7051	32.3948
Woman	5	4.2227	45.9637	2	6.3210	38.1194	2	6.2261	39.1929
	20	4.6486	38.5959	10	7.7963	37.9309	10	7.6525	38.9531
	40	4.7006	36.2422	60	8.2228	36.9150	60	8.0630	37.7032
Baboon	5	2.8919	45.0325	2	2.5360	28.3295	2	4.2336	31.2830
	20	4.0394	33.4290	10	5.5728	28.3070	10	5.1232	31.2387
	40	4.3563	28.5812	60	6.5171	27.7388	60	5.9105	30.1851
Pepper	5	3.3660	45.4495	2	5.4180	29.6425	2	5.2062	34.6061
	20	4.2134	35.6955	10	6.6467	29.6149	10	6.3308	34.5201
	40	4.4162	31.8072	60	7.2834	29.2953	60	6.9058	33.5990

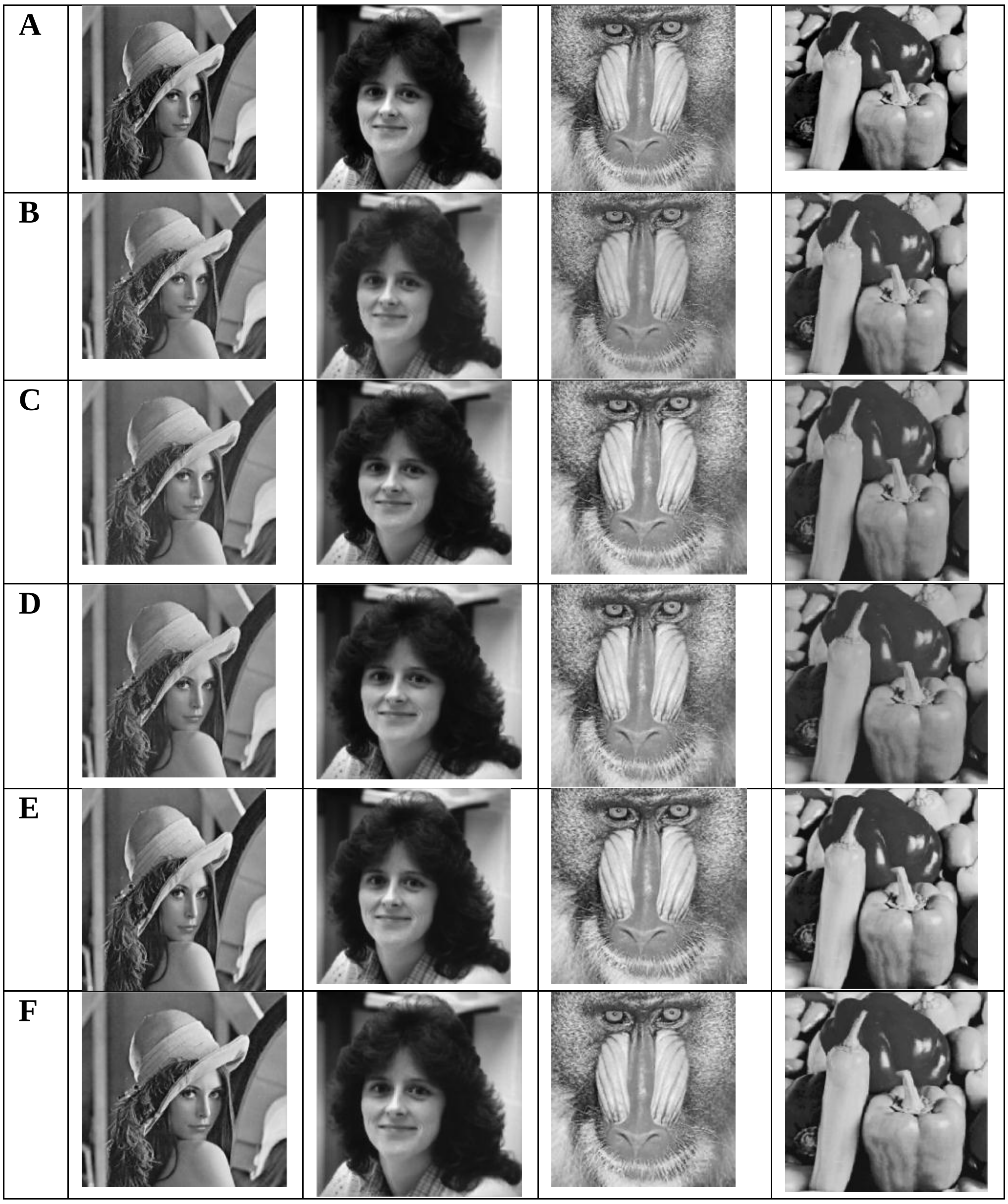

Figure 3- The compressed images using the traditional and adaptive techniques.
a- Traditional with Quantization Residual = 5 and Quantization Coefficients = 1,2,2.
b- Traditional with Quantization Residual = 60 and Quantization Coefficients = 1,2,2.
c- Hard Thresholding with Quantization Residual = 5 and Quantization Coefficients = 1,2,2.
d- Hard Thresholding with Quantization Residual = 60 and Quantization Coefficients = 1,2,2.
e- Soft Thresholding with Quantization Residual = 5 and Quantization Coefficients = 1,2,2.
f- Soft Thresholding with Quantization Residual = 60 and Quantization Coefficients = 1,2,2.

Conclusion

Clearly, the traditional polynomial coding of spatial base strongly affected by block sizes and quantization process of coefficients and residual. While the results show the adaptive proposed technique of hybrid base (spatial and frequency domain) improve compression ratio (*CR*) with preserving image quality especially with soft thresholding.

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