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Research Article

Image Compression Based on Cubic Bezier Interpolation, Wavelet Transform, Polynomial Approximation, Quadtree Coding and High Order Shift Encoding

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Abstract: In this study, an efficient compression system is introduced, it is based on using wavelet transform and two types of 3Dimension (3D) surface representations (i.e., Cubic Bezier Interpolation (CBI)) and 1st order polynomial approximation. Each one is applied on different scales of the image; CBI is applied on the wide area of the image in order to prune the image components that show large scale variation, while the 1st order polynomial is applied on the small area of residue component (i.e., after subtracting the cubic Bezier from the image) in order to prune the local smoothing components and getting better compression gain. Then, the produced cubic Bezier surface is subtracted from the image signal to get the residue component. Then, thebi-orthogonal wavelet transform is applied on the produced Bezier residue component. The resulting transform coefficients are quantized using progressive scalar quantization and the 1st order polynomial is applied on the quantized LL subband to produce the polynomial surface, then the produced polynomial surface is subtracted from the LL subband to get the residue component (high frequency component). Then, the quantized values are represented using quad tree encoding to prune the sparse blocks, followed by high order shift coding algorithm to handle the remaining statistical redundancy and to attain efficient compression performance. The conducted tests indicated that the introduced system leads to promising compression gain.

Keywords: Biorthogonal transform, cubic Bezier interpolation, polynomial approximation and shift coding

INTRODUCTION

By entering the digital age, the world has faced a vast amount of information. Dealing with this vast amount of information can often lead to numerous difficulties. Digital information must be stored, analyzed, retrieved and processed in an effective way, so as to be put to practical use (Raid *et al*., 2014). Uncompressed multimedia (graphics, video and audio) data requires very high bandwidth and considerable storage capacity in transfer. In order to manage large data objects efficiently, these objects need to be compressed to reduce the file size (Tripathi, 2014).

During the last several years, wavelet transformations have achieved widespread acceptance, particularly within image compression research**.** Wavelets are also chosen as the basic function in JPEG 2000 (Johnsen and Standeren, 2005).

Wavelets allow complex information such as images, speech, music and patterns to be decomposed into elementary forms at different positions and scales; and subsequently reconstructed with high précision (Sifuzzaman *et al*., 2009). For surveying the problem of improving image compression, a lot of methods have been developed.

Lin *et al*. (2008) presented a near lossless medical image compression scheme based on combined JPEG-Lossless Standard (JPEG-LS) with Cubic Spline Interpolation (CSI). It was developed to subsample image data with minimal distortion and to achieve image compression. The system led to higher subjective quality and high compression ratio when its results are compared with the outcomes of some standard transform-based codecs (Lin *et al*., 2008).

El-Harby and Behery (2008) presented an image compression algorithm based on dividing the original gray level image into un-overlapped blocks depending on a threshold value. The proposed algorithm is based on quad tree. It uses two stacks instead of a tree. The proposed algorithm stores the information of all blocks, for instance the size, upper left coordinate, minimum and difference values in a stack and the divided blocks are numbered in an effective way (El-Harby and Behery, 2008).

George and Sultan proposed a simple and hybrid method for compressing color image using wavelet

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transformation and 2D polynomial surface representation, the latter is utilized as a technique for reducing the large scale variation (or equivalently the low frequency component) associated with the image signal. Both wavelet trans form and polynomial representation followed by quantization and quad tree spatial coding and finally, shift encoder is applied as an efficient entropy encoder for further compression (Goerge and Sultan, 2011).

Al-Shereefi (2013) presented an image compression scheme based on using 2D daubechies wavelet transform and applying global threshold for the wavelet coefficients to minimize the computational requirements, the system aims to develop computationally efficient algorithms for loss image compression based on wavelet coding. The obtained results concerning with reconstructed image quality as well as maintaining the significant image details (Al-Shereefi, 2013).

Finally, Ahmed *et al*. (2015) proposed an efficient method for compressing color image using wavelet transform and Cubic Bezier Interpolation (CBI). The latter is utilized as a technique for pruning the image components that show large scale variation. Both wavelet and Bezier transforms are combined in high synthetic architect, followed by quantization and Quadtree spatial coding and finally, the results are further encoded using enhanced shift encoder as effective entropy encoder (Ahmed *et al*., 2015).

The objective of this study is to develop an efficient image compression system using two types of surface representation, CBI is applied on the whole area of the image to compensate the low variation components may exist in the image, the produced cubic Bezier surface is subtracted from the image signal to get the residue component, then the produced residue is decomposed using bi-orthogonal wavelet transform to transform the pixels in the residue image into frequency domain coefficients. The resulting transform coefficients are quantized using progressive scalar quantization and the 1st order polynomial is applied on the quantized LL subband to prune the local smoothing components, then the produced polynomial surface is subtracted from the LL subband to get the residue component (high frequency component). Then, the quantized values are represented using quad tree encoding to prune the sparse blocks, followed by an improved shift coding algorithm.

MATERIALS AND METHODS

When and where this study was conduct*: This study was conduct in university of Baghdad during master study (2015-2016).

The most common characteristic of the image signal is the presence of redundant information lies between the neighboring pixels. Compression tries to make the data de-correlated by remove this redundancy.

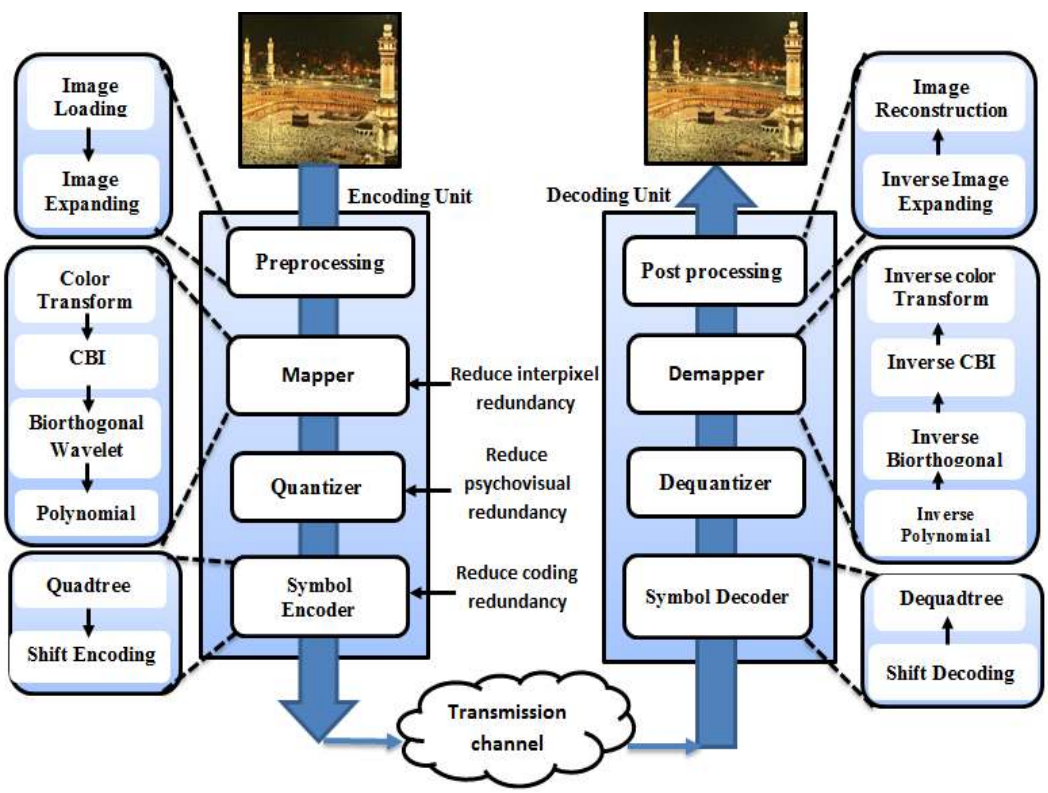


Fig. 1: The layout of proposed system (Encoding unit and decoding unit)

The typical image compression system contains three basic modules to accomplish image compression. Firstly, an appropriate transform (mapper) is applied to reduce interpixel redundancy. Secondly, the produced transform coefficients are quantized to reduce the psychovisual redundancy. Thirdly, the quantized values are coded using packed codes (symbol encoder) to reduce coding redundancy (Katz and Gentile, 2006).

Figure 1 presents the layout of the proposed system (encoding unit and decoding unit). Figure 2 and 3 illustrate the main steps of the encoding unit. The description of each module belongs to the encoding unit is explained in the following subsections.

Preprocessing module: This module is responsible for the preparation of the image data, such that the subsequent stages of the system can operate, effectively.
The preprocessing module consists of two main stages:

- **Image loading:** Image data are loaded and separated into three (R, G and B) color arrays.
- **Image Expansion and partitioning:** In this stage, the three extracted arrays (R, G and B) are expanded horizontally and vertically, if it is needed, according to the predefined block length (L_b), so that the width and height values of the expanded image must be multiples of block size value as illustrated in Fig. 4. Image expansion is done using the following steps:

$$N_x = \left\lceil \frac{W+L_b-1}{L_b} \right\rceil \quad (1)$$

$$W1 = N_x \times L_b \quad (2)$$

$$n_{column} = W1 - W \quad (3)$$

$$N_y = \left\lceil \frac{H+L_b-1}{L_b} \right\rceil \quad (4)$$

$$H1 = N_y \times L_b \quad (5)$$

$$n_{row} = H1 - H \quad (6)$$

where,
N_x, N_y = The number of blocks aligned horizontally; vertically, respectively,
$W1$ = The new width value
$H1$ = The new height value

RGB to YUV color transform: In this step, the components (R, G and B) are transformed into less correlated color space components (YUV), in order to reduce the spectral redundancy and get better compression gain, since the human eye is not as sensitive to high frequency chrominance information (U and V) as it is to high frequency luminance Y, then the produced chrominance bands are down sampled by 2 to produce the down sampled components (U_d and V_d), which lead to an overall reduction in image size to quarter, with nearly no impact on perceived image quality.

Pruning the Large Scale Variation of the Image: In this step, the components that show large scale variation of the image bands (Y, U_d and V_d) are pruned, individually. These components are pruned by representing the image data in terms of smooth surface using Cubic Bezier Interpolation (CBI) (as illustrated in Fig. 5).

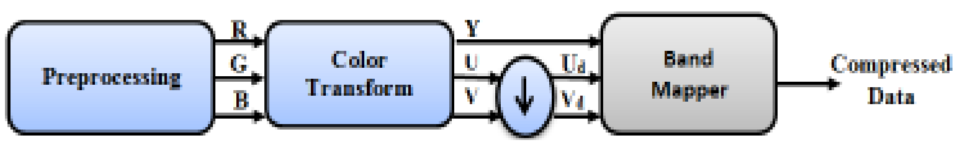


Fig. 2: The layout of encoding unit

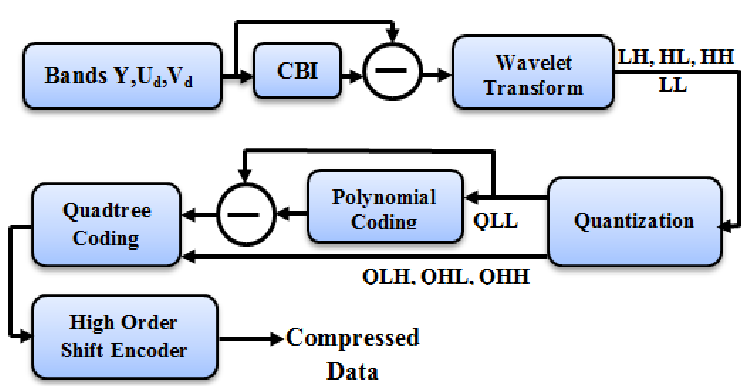


Fig. 3: Band mapper

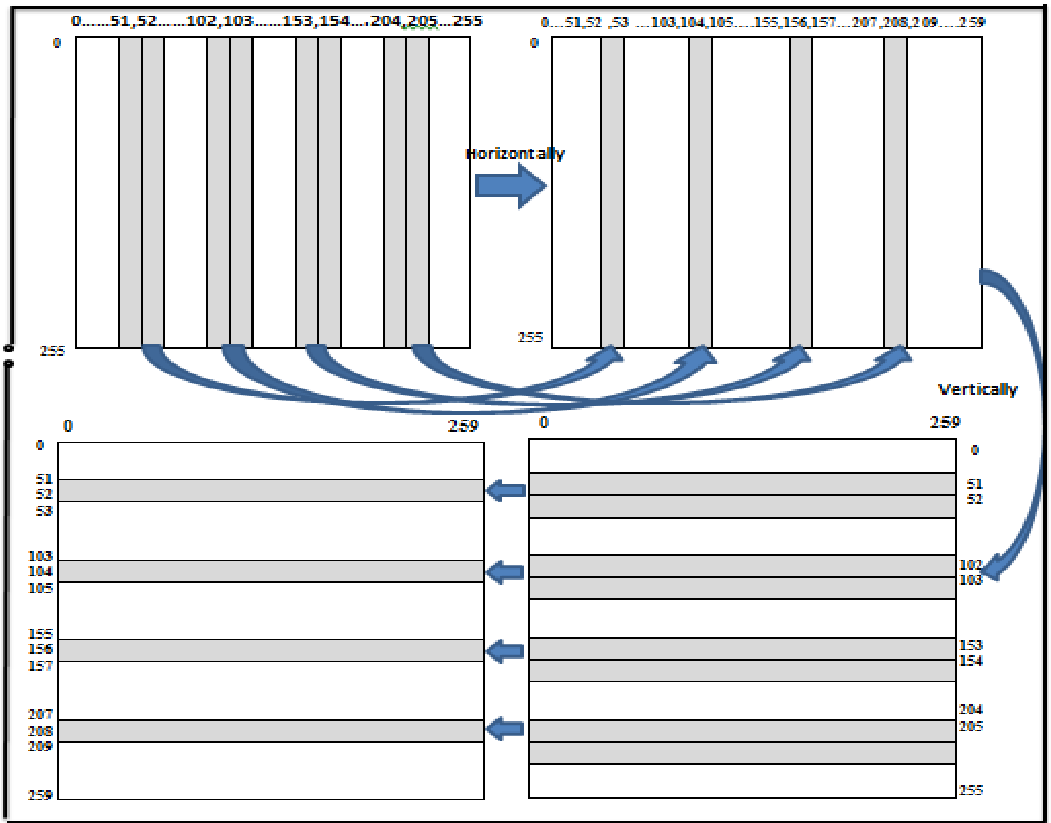


Fig. 4: Image expansion process when the image size is (256×256) and block size is (5×5)

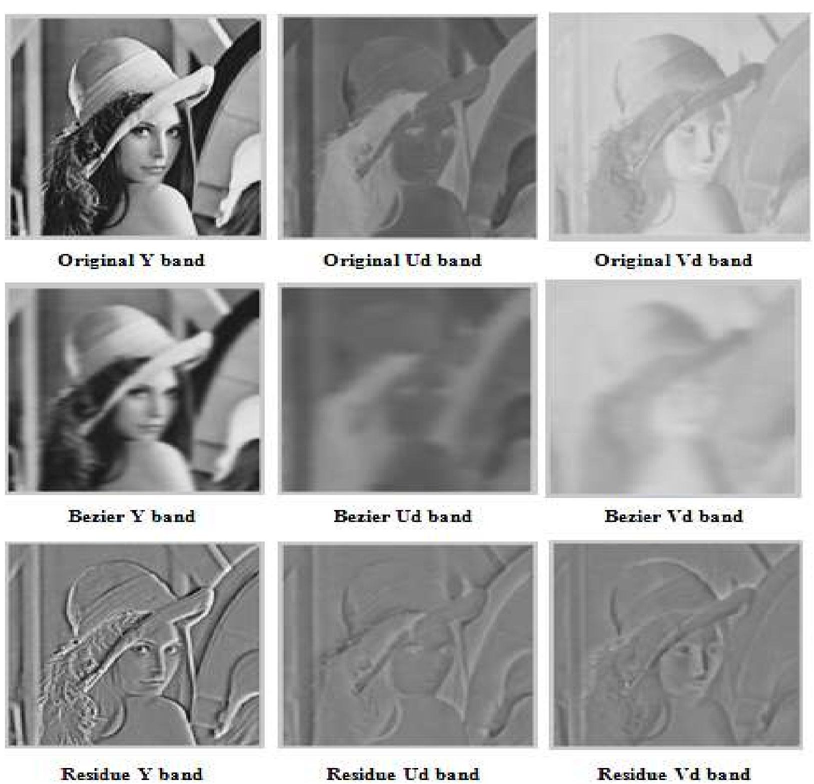


Fig. 5: The original, Bezier and residue components of (Y, U_d and V_d) bands

This representation is accomplished by partitioning each band into a non-overlapped blocks, each has length (8×8) pixels. Then the following steps are applied:

- Compute the mean value of each block.
- Apply cubic Bezier equation for each block, such that for a block has the indexes (Ix ϵ [0, Nx-1], Iy ϵ [0, Ny-1]) take the surrounding neighboring blocks have the indexes [Jx, Jy] to establish the Bezier surface. The range of values of Jx and Jy is selected to be:

$$J_x = \begin{cases} [0,3] \text{ If } I_x < 2 \\ [I_x - 1, I_x + 2] \text{ If } 2 \le I_x \le N_x - 3 \\ [N_x - 4, N_x - 1] \text{ If } I_x > N_x - 3 \end{cases} \quad (7)$$

$$J_y = \begin{cases} [0,3] \text{ If } I_y < 2 \\ [I_y - 1, I_y + 2] \text{ If } 2 \le I_y \le N_y - 3 \\ [N_y - 4, N_y - 1] \text{ If } I_y > N_y - 3 \end{cases} \quad (8)$$

Biorthogonal tap 9/7 wavelet transform coding: In this step, the Bezier residual components of Y_R, U_{dR} and V_{dR} are decomposed to four known subbands, separately, by applying bi-orthogonal tap 9/7 wavelet filters, each subband holds certain kind of image information.

Progressive scalar quantization: At this stage, progressives scalar quantization is applied on the produced wavelet coefficients (LL, LH,HL and HH), where the quantization step (Q_S) used to quantize the approximate subband (LL) is set to (1), while the Q_S used to quantize the coefficients of each detail subband (LH, HL and HH) was determined according to the following equation:

$$Q_s = \begin{cases} Q\alpha^{n-1} \text{ for LH, HL in } n^{th} \text{ Level} \\ Q\beta\alpha^{n-1} \text{for HH in } n^{th} \text{ Level} \end{cases} \quad (9)$$

where, *n* is the number of wavelet passes, the value of the quantization step is decreased using progressive, linear relationship and its value for HH subband is greater than its value for the corresponding HL and LH subbands because it is multiplied with β. So, the quantization indexes for approximate and wavelet coefficients are determined by using the following equation:

$$W_Q(x, y) = \text{round}\left(\frac{W_C(x,y)}{Q_S}\right) \quad (10)$$

where,
$W_C()$ = The array of wavelet transform coefficients
$W_Q()$ = Its quantization index array.

Pruning the local smoothing components: In this step, the polynomial approximation is applied on LL subbands of the Bezier residual parts of (Y_R, U_{dR} and V_{dR}), individually; the polynomial approximation is performed to prune the local smoothing components. It has been accomplished by partitioning LL subband into a non-overlapped blocks,each has predefined length (L_b×L_b) pixels. Then the following steps are applied:

- Compute the polynomial coefficients of each LL residual part block according to Eq. (11, 12, 13and14), which were used to compute the optimal values of polynomial coefficients.
- The determined polynomial coefficients are used to construct the polynomial part of the block and it is subtracted from the Bezier residue values in order to compute the residue component. Figure 6 shows the polynomial residual of LL subband for Lena image.

$$a_0 = \frac{\sum_{y=0}^{y=L_b-1} \sum_{x=0}^{x=L_b-1} B_r(x,y)}{{L_b}^2} \quad (11)$$

$$a_1 = \frac{\sum_{y=0}^{y=L_b-1} \sum_{x=0}^{x=L_b-1} (x-x_c)\times B_r(x,y)}{\sum_{y=0}^{y=L_b-1} \sum_{x=0}^{x=L_b-1} (x-x_c)^2} \quad (12)$$

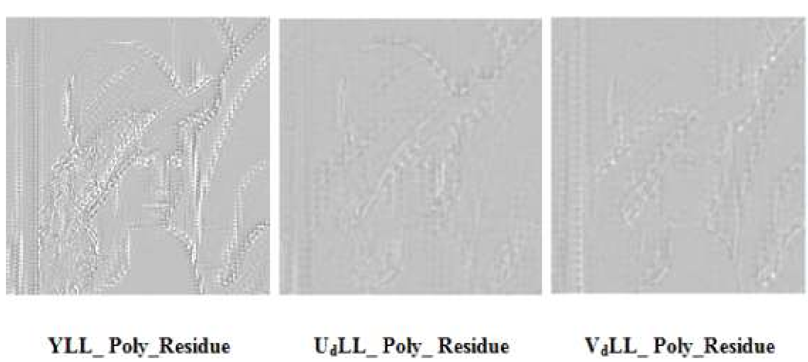


Fig. 6: The polynomial residual of LL subband for (Y, Ud and Vd)

$$a_2 = \frac{\sum_{y=0}^{y=L_b-1}\sum_{x=0}^{x=L_b-1}(y-y_c)\times B_r(x,y)}{\sum_{y=0}^{y=L_b-1}\sum_{x=0}^{x=L_b-1}(y-y_c)^2} \quad (13)$$

$$x_c = y_c = \frac{1}{2}(L_b - 1) \quad (14)$$

where, a_0, a_1 and a_2 are the i^{th} polynomial coefficients, The residue component is calculated according to the following equations:

$$N(x,y) = a_0 + a_1 (x-x_c) + a_2 (y-y_c) \ \forall x,y \quad (15)$$

$$Re(x,y) = O(x,y) - N(x,y) \ \forall x,y \quad (16)$$

where, $N(x, y)$ is the polynomial part for each ($L_b \times L_b$), $O(x, y)$ is the original image values for each ($L_b \times L_b$) block, $Re(x, y)$ is the residue value at (x, y).

Quad tree coding: In this step, Quadtree coding is applied on each quantized detail subband (i.e., LH, HL and HH) and polynomial residual of LL subband of (Y_R, U_{dR} and V_{dR}) bands. In this coding method, the input band is, initially, partitioned into non-overlapped square blocks. Then, each non-empty block is partitioned into equal sized square blocks. The emptiness criterion is the values of all pixels belong to the tested block are zero (i.e., no pixels hold non-zero values). In case the tested block is not empty then the search is repeated upon its four daughter quadrants. This process is repeated, recursively, starting from the image and continuing till reaching the smallest block size (i.e., 2×2 block), as illustrated in Fig. 7. If it is a non-empty block, then its contents are saved in a buffer beside to the quad tree coding sequence.

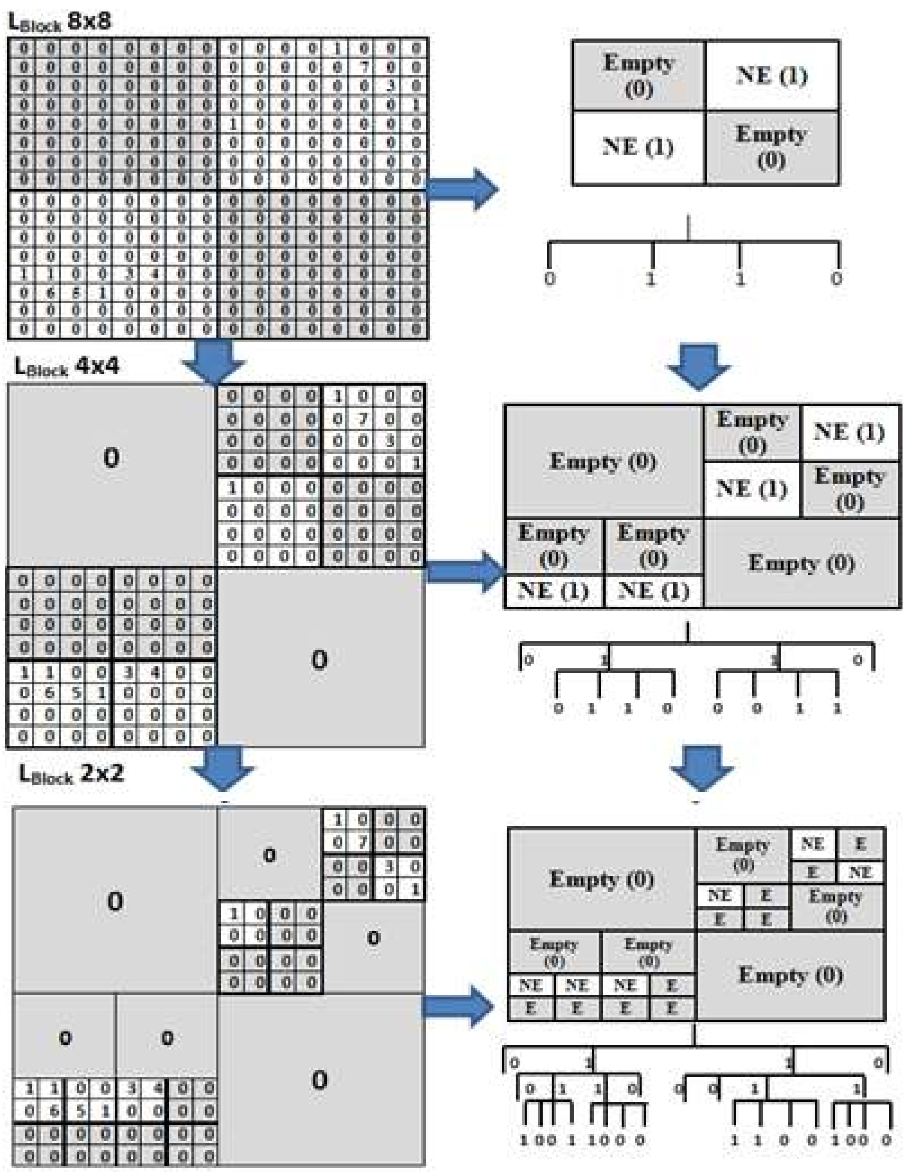


Fig. 7: An illustrative example to clarify the quadtree coding process

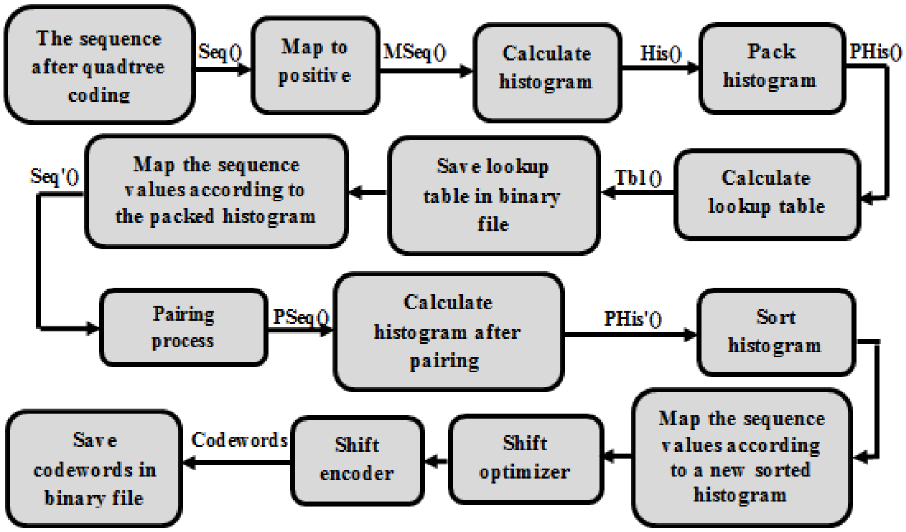


Fig. 8: High order shift encoder

High order shift encoder: The developed shift encoder has been applied, as the last step of encoding unit, on the output sequence coming from quadtree stage (as explained in Fig. 8). The established method consists of the following steps:

- Map elements' values to be always positive.
- Pack the histogram range of input elements has valued to be always is not shown long tail around zero.
- Determine the most frequent pairs of successive values and replace each pair with a new symbol (i.e., Max+1; where Max is the highest coefficient value before pairing).
- Shift coding optimizer is applied to determine the optimal lengths of the long and short code words. The applied shift coding optimizer uses Eq. (17 and 18) to determine the total number of consumed bits:

$$Tot = (n_s + 1)\sum_{i=0}^{2^s-1} His(i) + (n_l + 1)\sum_{i=2^s}^{L} His(i) \quad (17)$$

$$orTot = n_s \sum_{i=0}^{2^s-2} His(i) + (n_s + n_l)\sum_{i=2^s-1}^{L} His(i) \quad (18)$$

where the values of n_s and n_l represent the length of short and long code words respectively, that leads to the minimum possible value for Tot. The array His() represents the histogram array.

To reconstruct the decompressed image, same stages used in encoding unit were applied but in reverse order.

Table 1: The default values of the control parameters

Parameter	Default value Lena (8/24)	Barbara(8/24)	Range
Qs	20	10	[10,50]
α	0.3	0.4	[0.1,0.9]
β	1.8	1.8	[1,1.9]
N_{pass}	3	3	[1,4]
L_b	6	6	[4,8]

RESULTS AND DISCUSSION

Many sets of tests have been performed to assess our work in termsof Compression Ratio (CR), Peak Signal to Noise Ratio (PSNR), Encoding Time (ET) and Decoding Time (DT).As image test samples Lena (with size 256x256 pixel, pixel color depth =8/24 bit) and Barbara image (with size= 256x256 pixel, pixel color depth=8/24 bit) have been used. The effects of the following control parameters have been investigated:

- The number of wavelet passes (N_{pass})
- Beta multiplication parameter (β)
- Descending rate parameter (α)
- Block size (L_b)
- Initial quantization step (*Qs*) for subbands coefficients (LH, HL and HH)

Table 1 shows the adopted default values of the considered control parameters. The effect of each involved coding parameter is explored by varying its value while keeping the values of other parameters fixed at their default values.

Table 2 to 5 list the compression results with different values of N_{Pass} for Color Lena, Gray Lena, Color Barbara and Gray Barbara images, respectively.

The above results indicate that the increase of N_{Pass} leads to high compression gain while causes decrease in PSNR value when N_{Pass} was set (=1, 2 or 3), while the attainted compression gain is decreased insignificantly

Table 2: Test results for color lena image

Npass	CR	PSNR	MSE	CG	ET	DT
1	7.730	32.15	39.68	0.87	0.410	0.038
2	16.02	30.15	62.86	0.94	0.268	0.038
3	18.23	29.65	70.49	0.95	0.256	0.040
4	17.80	28.58	90.11	0.94	0.329	0.042

Table 3: Test results for gray lena image

Npass	CR	PSNR	MSE	CG	ET	DT
1	3.18	34.30	24.13	0.69	0.367	0.029
2	5.94	31.99	41.10	0.83	0.277	0.030
3	6.25	31.29	48.33	0.84	0.310	0.033
4	6.11	29.90	66.50	0.84	0.300	0.035

Table 4: Test results for color barbara image

Npass	CR	PSNR	MSE	CG	ET	DT
1	6.280	32.42	37.26	0.84	0.723	0.044
2	9.780	30.79	54.26	0.90	0.749	0.043
3	10.31	30.24	61.55	0.90	0.946	0.046
4	10.13	29.55	72.10	0.90	1.093	0.080

Table 5: Test results for gray barbara image

Npass	CR	PSNR	MSE	CG	ET	DT
1	2.46	37.15	12.53	0.59	0.544	0.031
2	3.52	34.88	21.16	0.72	0.788	0.033
3	3.54	33.94	26.27	0.72	1.015	0.036
4	3.52	32.11	40.02	0.72	1.185	0.036

Table 6: Comparison between the compression results of some standard coders and the proposed system used to encode color Lena image

Tested image	Method	Controlled parameter					CR	PSNR	MSE
Color	JPEG	Quality							
Lena	standard	20%					23.35	30.77	54.44
		40%					21.59	31.60	44.93
		80%					10.32	34.56	22.72
	JPEG 2000						23	33.75	27.38
							21	34.20	24.67
							10	38.64	8.870
	Proposed	N_{pass}	L_b	β	α	Qs	CR	PSNR	MSE
	System	3	8	1.3	0.3	30	23.02	28.01	102.59
		3	8	1.6	0.4	20	21.93	28.38	94.210
		2	4	1.5	0.2	10	10.3	32.84	33.790

Table 7: Comparison between the compression results of some standard coders and the proposed system used to encode Gray Lena image

Tested Image	Method	Controlled parameter					CR	PSNR	MSE
Gray	JPEG	Quality							
Lena	Standard	10%					8.86	31.6	44.95
		60%					5.51	34.59	22.55
		90%					2.48	41.85	4.23
	JPEG 2000						8	46.05	1.610
							5	49.17	0.780
							2	49.17	0.780
	Proposed	N_{pass}	L_b	β	α	Qs	CR	PSNR	MSE
	System	3	8	1.9	0.2	40	8.25	29.12	79.51
		2	8	1.6	0.3	20	6.02	32.14	39.64
		1	8	1	0.1	10	2.72	38.12	10.01

Table 8: Comparison between the compression results of some standard coders and the proposed system used to encode color Barbara image

Tested Image	Method	Controlled parameter					CR	PSNR	MSE
Color	JPEG	Quality							
Barbara	Standard	40%					14.43	30.45	69.48
		70%					10.72	32.46	36.84
		80%					8.6	33.97	26.03
	JPEG 2000						14	34.19	24.77
							10	36.35	15.04
							8	38.06	10.14
	Proposed	N_{pass}	L_b	β	α	Qs	CR	PSNR	MSE
	System	2	8	1.9	0.3	20	14.22	28.00	103.0
		2	8	1.8	0.4	10	10.09	30.78	54.27
		2	4	1.5	0.2	10	8.10	32.08	40.23

when N_{Pass} was set 4. Also, it is obvious that a tradeoff among system performance measures was achieved when N_{Pass} is set 3.

The results of our proposed system have been compared with the standard JPEG and JPEG2000 in order to measure its efficiency. Table 6 to 9 show the compression results of CR, PSNR and MSE values which are attained by our proposed method with those given in standard encoder for all tested images, taking into consideration that different image quality has been used. The listed results demonstrate that our proposed method is competitive to the image standard compression methods.

Figure 9 to 12 show part of the reconstructed images: Color Lena, Gray Lena, Color Barbara and Gray Barbara, respectively, where the compression parameters are taken and highlighted in Table 6 to 9, respectively.

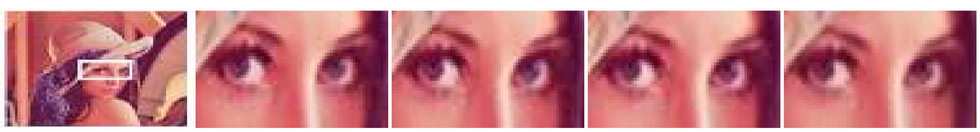
CONCLUSION

In this study, an image compression system based on using wavelet transform and two types of 3D surface representation (i.e., CBI and polynomial approximation), quadtree and high order shift coding had been introduced. The conducted test results indicated that the proposed system is promising and the following remarks are stimulated:

- The use of 2D polynomial approximation on the Bezier residual part of an image had improved the compression performance (i.e., increase the compression gain while preserving the image quality)
- The increase in the quantization step causes an increase in compression ratio and decrease in PSNR value.

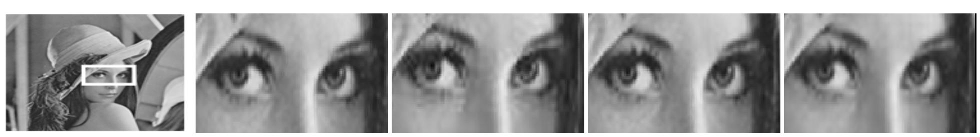
Table 9: Comparison between the compression results of some standard coders and the proposed system used to encode Gray Barbara image

Tested Image	Method	Controlled parameter					CR	PSNR	MSE
Gray Barbara	JPEG Standard	Quality							
		30%					6.50	30.82	53.74
		80%					3.28	37.89	10.54
		90%					2.35	42.65	3.53
	JPEG 2000						6.00	48.98	0.69
							3.00	49.46	0.69
							2.00	49.72	0.69
	Proposed System	N_{pass}	L_b	β	α	Qs	CR	PSNR	MSE
		2	8	1.9	0.2	30	6.03	29.65	70.46
		2	8	1	0.2	20	4.16	32.86	33.59
		1	8	1	0.1	10	2.41	38.01	10.27



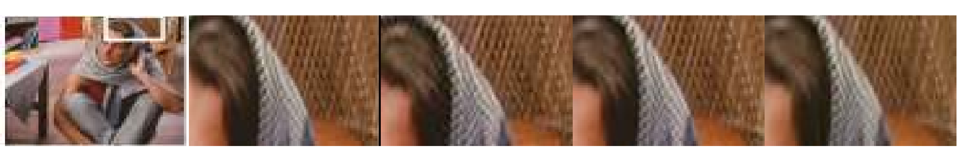
(a) (b) (c) (d) (e)

Fig. 9: Part of the reconstructed color Lena image sample, the compression parameters are taken and highlighted in Table 6; (a): Original color lena image; (b): Original; (c): JPEG; (d): JPEG2000; (e): Proposed system



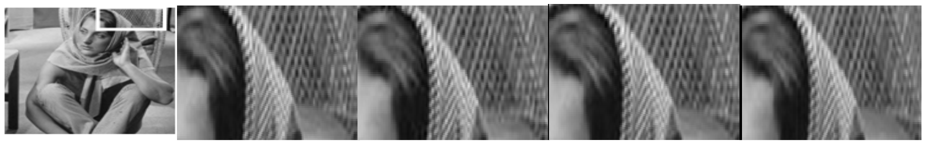
(a) (b) (c) (d) (e)

Fig. 10: Part of the reconstructed gray Lena image sample, the compression parameters are taken and highlighted in Table 7; (a): Original gray lena image; (b): Original; (c): JPEG; (d): JPEG2000; (e): Proposed system



(a) (b) (c) (d) (e)

Fig.11: Part of the reconstructed color Barbara image sample, the compression parameters are taken and highlighted in Table 8; (a): Original color barbara image; (b): Original; (c): JPEG; (d): JPEG2000; (e): Proposed system



(a) (b) (c) (d) (e)

Fig. 12: Part of the reconstructed gray Barbara image sample, the compression parameters are taken and highlighted in Table 9; (a): Original gray barbara image; (b): Original; (c): JPEG; (d): JPEG2000; (e): Proposed system

- As a future work the developed system can be improved by applying hierarchal partitioning instead of fixed block size partitioning according to details of image regions, also, a no uniform quantization can be applied to get better compression gain.

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