JPEG-Like Color Image Compression Based on All Phase Biorthogonal Transform and Improved Quantization Table

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Abstract —With the development of multimedia technologies, color image compression requires higher performance. To address this need and fit the human visual system (HVS), this paper adopts the improved luminance quantization table obtained by duality nonlinear programming and the uniform chrominance quantization table, which are applied to JPEG-like color image compression algorithm based on all phase biorthogonal transform (APBT). Besides, we also apply proposed compression algorithm to deal with color filter array (CFA) image data. All experimental results show that our algorithm ensures the slightest increase of computational complexity and improves the quality of the color image. The blocking artifacts also have been partly removed, especially at low bit rates. In general, the proposed algorithm can produce optimal rate-distortion and better subjective image quality compared with some existing methods.

Index Terms—Color image coding, All Phase Biorthogonal Transform (APBT), duality nonlinear programming, optimized adaptive interpolation, Composite Peak Signal to Noise Ratio (CPSNR)

I. Introduction

With the continual expansion of applications of multimedia, the needs and requirements of the technologies used, grew and evolved. The JPEG2000 standard [1] represents the current state-of-the-art coder for still images. For still images, the gray-scale image uses a single value per pixel that is called intensity or brightness. But according to characteristics of human vision, we can only identify a dozen gray levels. However, thousands of tones or shades can be distinguished by our eyes easily. That is why the color image is used widely in all domains. A great deal of effort trying to study and develop color image compression algorithm, has been taken. The compression algorithm includes two types, which are lossless and lossy. In Ref. [2], a perceptual color image coder was presented for the YCbCr color space within the framework of JPEG2000, which employed a vision model based on perceptual distortion metric to approximate perceived error for rate-distortion optimization in order to maximize the visual quality of coded images. The Mean Squared Error (MSE) and the visual distortion metric were as distortion measures. Wang *et al*. [3] proposed a novel color image compression algorithm based on All Phase Biorthogonal Transform (APBT). Zhang *et al*. [4] proposed a color image compression algorithm based on directional APBT. Alzahir and Borici [5] presented an innovative method of lossless compression for discrete-color images. The results showed that their method compresses images from both categories (binary and discrete color images) with 90% in most cases and higher than the JBIG-2 by 5%~20% for binary images, and by 2%~6.3% for discrete color images on average. Moreover, nonlinear programming [6]-[8] is widely used in engineering, economy, management, scientific research, military and other aspects, which provides a powerful tool for optimal design.

In this paper, we propose a novel color image compression algorithm with improved luminance quantization table by using duality nonlinear programming method [9]. Our algorithm is a JPEG-like image compression algorithm based on APBT, which includes All Phase Walsh Biorthogonal Transform (APWBT), All Phase Discrete Cosine Biorthogonal Transform (APDCBT) and All Phase Inverse Discrete Cosine Biorthogonal Transform (APIDCBT) [10]. For chrominance quantization table, we adopt uniform quantization step considering the high frequency attenuation property of APBT. Our scheme ensures the slightest increase of computational complexity and improves the quality of the color image. The blocking artifacts also have been partly removed, especially at low bit rates. In addition, further research on CFA image compression based on our scheme has been studied.

The rest of this paper is organized as follows. Section II describes DCT-based JPEG image compression algorithm. We propose an improved compression algorithm based on APBT for color image in Section III. Experimental results and analysis are presented in Section IV. Conclusions and remarks on possible further work are given finally in Section V.

II. DCT-based JPEG Image Compression Algorithm (DCT-JPEG)

The block diagram of color image compression algorithm based on DCT is illustrated in Fig. l. The forward DCT (FDCT) is first applied on the original color image data. The transform coefficients are then quantized,

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zig-zag scanned, and entropy coded before forming the output bit stream. The decoder is the reverse of the encoder, which thus obtains the reconstructed color image data. Fig. 2(a) and (b) display the luminance and chrominance quantization tables respectively.

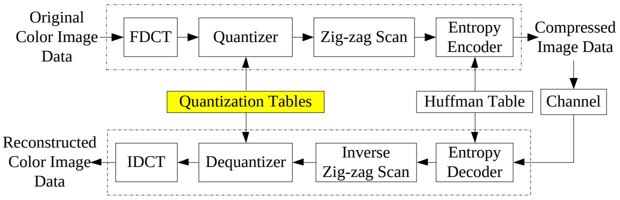


Fig. 1. Diagram of color image compression algorithm based on DCT.

(a)

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

(b)

17	18	24	47	99	99	99	99
18	21	26	66	99	99	99	99
24	26	56	99	99	99	99	99
47	66	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99

Fig. 2. Quantization tables: (a) luminance quantization table, and (b) chrominance quantization table.

III. JPEG-Like Color Image Compression Algorithm Based on APBT (APBT-JPEG)

At present, many new transforms of image compression and optimization methods of quantization table have been proposed. DCT is not necessarily the best option in image compression. Hou *et al.* [10] proposed a new transform – APBT which is applied to image processing. In the following, we will introduce our JPEG-like image compression algorithm based on APBT, which employs improved quantization table.

A. Introduction of All Phase Biorthogonal Transform

In order to reduce the shortcomings of digital filter, the all phase DFT digital filter was designed in Ref. [11]. Based on the All Phase Digital Filtering (APDF) theory, three kinds of APBTs based on the WHT, DCT and IDCT were obtained [10]. They are called APWBT, APDCBT, and APIDCBT respectively. In Ref. [10], the matrices of these three APBTs were deduced, which all are full rank matrices. Take for example, the transform matrix of APIDCBT with size of $N\times N$ is shown in (1):

$$V(m,n)=\begin{cases}\dfrac{1}{N}, & m=0,\ n=0,1,\cdots,N-1,\\[2ex] \dfrac{N-m+\sqrt{2}-1}{N^2}\cos\dfrac{m(2n+1)\pi}{2N}, & m=1,2,\cdots,N-1,\ n=0,1,\cdots,N-1.\end{cases} \quad (1)$$

The value of N is 8 when we apply 8×8 block transform. APBTs have a better ability of energy compaction in image compression than DCT, which have been not only applied to gray-scale image compression [10], but also to image demosaicking [12], [13] and video compression [14], [15]. Fig. 3 shows the basic process of gray-scale image compression algorithm based on APBT. APBT has the better energy compaction characteristic in image compression than DCT, which means that the low frequency components can be compacted even more than high frequency components. So uniform quantization step has superseded JPEG default quantization table.

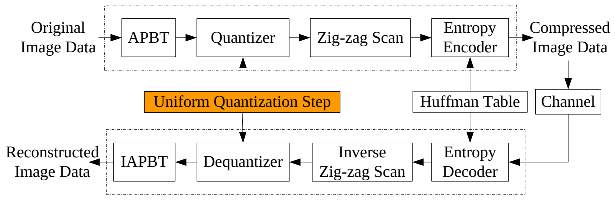


Fig. 3. Diagram of image compression algorithm based on APBT.

B. Transformations between RGB and YCbCr Color Models

In addition to APBT-JPEG of gray-scale image, Wang *et al.* [3] studied a novel compression algorithm of color image. The only difference between them is that color image algorithm needs transformation of color models from RGB to YCbCr. The YCbCr is the corresponding standard for digital video and it is the most used color model in the computer system. Since this standard separates luminance, thus it has been used for digital compression encoding formats like Joint Photographic Expert Group (JPEG) and Moving Pictures Expert Group (MPEG). The data reduction is implemented by having less samples of chrominance than luminance. This color model has been developed for digital photography and it is commonly used in digital cameras.

Thus we first transform RGB to YCbCr. The forward and the inverse Irreversible Component Transformation (ICT) are achieved by means of (2) and (3) respectively.

$$\begin{bmatrix}Y\\Cb\\Cr\end{bmatrix}=\begin{bmatrix}0.299 & 0.587 & 0.114\\-0.169 & -0.331 & 0.500\\0.500 & -0.419 & -0.081\end{bmatrix}\begin{bmatrix}R\\G\\B\end{bmatrix}+\begin{bmatrix}0\\128\\128\end{bmatrix} \quad (2)$$

$$\begin{bmatrix}R\\G\\B\end{bmatrix}=\begin{bmatrix}1.0 & 0 & 1.402\\1.0 & -0.34413 & -0.71414\\1.0 & 1.772 & 0\end{bmatrix}\begin{bmatrix}Y\\Cb\\Cr\end{bmatrix} \quad (3)$$

Overall, using YCbCr can make full use of Human Visual System (HVS). So we adopt transformation from RGB to YCbCr in this paper, as shown in Fig. 4. Then the luminance component Y and chrominance components Cb, Cr are separated and undergone our improved APBT-JPEG compression algorithm respectively. The proposed APBT-JPEG adopts improved luminance quantization table which will be introduced in the next part.

C. Nonlinear Programming Method Applied to Improve Luminance Quantization Table

Although uniform quantization method reduces the computational complexity, it is rough and not the best choice for improving the quality of reconstructed images at the same bit rate. The study of Ivanov [9] on nonlinear programming provides theoretical support for improving quantization table. On the basis of HVS, human eyes are sensitive to luminance details and insensitive to color details. This has greatly reduced the bandwidth of chrominance signals. So we employ nonlinear programming method to improve the luminance quantization table. And the chrominance quantization table still uses the uniform quantization step. Because APBT-JPEG of color image adopts both luminance and chrominance uniform quantization tables. But the proposed algorithm just adopts uniform quantization table on chrominance components while the luminance component adopts the improved quantization table, which increases the computational complexity slightly. That would cause noticeably improvement of image quality with the slightest increase of computational complexity.

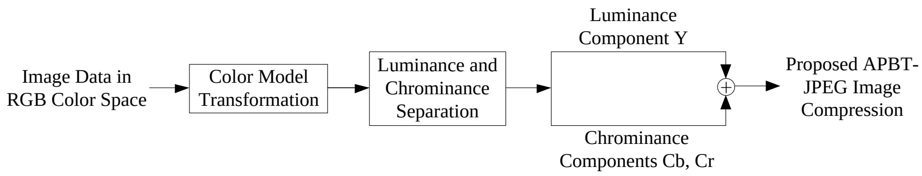


Fig. 4. Diagram of luminance and chrominance separation.

The nonlinear programming is to study the extremum problems under the constraints of a set of equations or inequalities, and at least one of the objective functions and the constraints is the unknown nonlinear function. Each coefficient S_{vu} is obtained after the APBT being computed for a block. The quantization step size for each S_{vu} is the value of the corresponding element Q_{vu} in the improved quantization table. The process of uniform quantization is defined by (4):

$$Sq_{vu} = round\left(\frac{S_{vu}}{Q_{vu}}\right),\ 1 \le Q_{vu} \le 255,\ 1 \le v \le 8,\ 1 \le u \le 8 \qquad (4)$$

where *round* is to get the nearest integer, and Sq_{vu} is the quantized APBT coefficient, normalized by the quantization step size. At the decoder, the normalization is removed by (5), which defines dequantization.

$$R_{vu} = Sq_{vu} \times Q_{vu},\ 1 \le Q_{vu} \le 255,\ 1 \le v \le 8,\ 1 \le u \le 8 \qquad (5)$$

where R_{vu} is the value after dequantization.

Maximize the composite peak signal to noise ratio (CPSNR) to achieve an optimal value as (6). After entropy coding, we define quantization distortion D_{q} and number of bits N_{b} as the constraints in (7). Consider the linear programming problem with a variable Q_{vu}, which is the variable of functions g and f,

$$\text{maximize CPSNR} = g(Sq_{vu}) \qquad (6)$$

$$\text{subject to} \begin{cases} D_{\mathrm{q}} = \sum_{v}\sum_{u}(R_{vu} - S_{vu})^2, \\ N_{\mathrm{b}} = \sum_{v}\sum_{u} f(Sq_{vu}). \end{cases} \qquad (7)$$

With the nonlinear programming, we can get the overall solution, while most of the existing solutions just give the local solution. Taking into account of the uncertainties of the decision variables and the computational complexity, the optimal solution can be achieved by the experimental methods. When the value of PSNR gets maximum, the quantized element is obtained. Remaining quantized element is tested one by one and fixed in accordance with the zig-zag scanning order. Observing the overall effect brought by adjustment, we can get an improved quantization table, shown in Fig. 5.

D. Improved Quantization Table Applied in Color Image Compression Based on APBT

Compared with the DCT-based JPEG image compression algorithm, the APBT matrix is used to reduce interpixel redundancy. We also propose improved luminance quantization table according to HVS, which can improve image quality with almost no extra burden on complexity. Due to human eyes are more sensitive to luminance, uniform step is used as chrominance quantization. The use of the uniform chrominance quantization step reduces the computational complexity. Fig. 6 shows the diagram of the proposed color image compression algorithm based on APBT.

33	28	28	22	22	19	19	19
31	23	18	20	19	19	19	19
29	20	22	19	19	19	19	19
21	19	19	19	19	19	19	19
19	19	19	19	19	19	19	19
19	19	19	19	19	19	19	19
19	19	19	19	19	19	19	19
19	19	19	19	19	19	19	19

Fig. 5. Improved luminance quantization table.

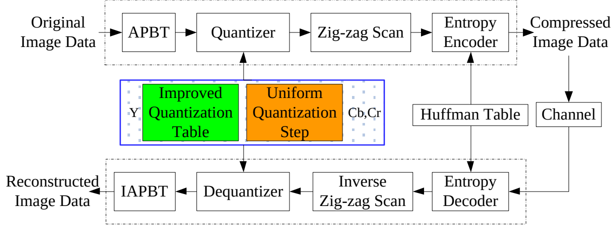


Fig. 6. Diagram of proposed color image compression algorithm based on APBT.

E. Application of the Proposed APBT-JPEG Scheme in CFA

In the practical application, many consumer digital cameras achieve the the process of obtaining color image by using a single sensor and a color filter array (CFA). In Ref. [16], Zhou *et al*. proposed an optimized adaptive interpolation method using directional weighting. Through calculating the horizontal color difference D_{H} , vertical color difference D_{V} , positive diagonal difference D_{P} and negative diagonal difference D_{N} separately, the weighting coefficients of the horizontal gradient, vertical gradient, negative diagonal and positive diagonal weighting coefficients can be got. They are defined as W_{H} , W_{V}, W_{N} , and W_{P} in (8)~(11), respectively.

$$W_{\mathrm{H}} = D_{\mathrm{V}} / (D_{\mathrm{H}} + D_{\mathrm{V}}) \quad (8)$$

$$W_{\mathrm{V}} = D_{\mathrm{H}} / (D_{\mathrm{H}} + D_{\mathrm{V}}) \quad (9)$$

$$W_{\mathrm{N}} = D_{\mathrm{P}} / (D_{\mathrm{N}} + D_{\mathrm{P}}) \quad (10)$$

$$W_{\mathrm{P}} = D_{\mathrm{N}} / (D_{\mathrm{N}} + D_{\mathrm{P}}) \quad (11)$$

The missing R, G, B pixels could be calculated by using these weighting coefficients.

This interpolation method could suppress the zipper artifact and false color artifact. But their work was not involved the baseline JPEG compression. With the good performance of Zhou's interpolation method, we combine our compression aigorithm with Zhou's metohd to test the applicability of our algorithm. So we conduct preliminary exploration of the application of our APBT-JPEG in CFA. In order to avoid data redundancy and reduce the burden of transmission channel, we first compress the CFA data. Finally, in the receiver, the full color image is reconstructed through interpolation. Fig. 7 shows the overall diagram of CFA data compression based on the proposed APBT-JPEG.

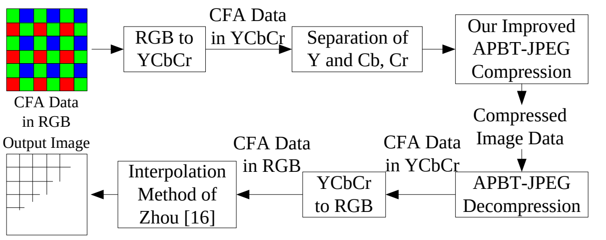


Fig. 7. Diagram of CFA data compression algorithm based on our APBT-JPEG.

IV. Experimental Results and Analysis

In this section, the efficiency of our algorithm in comparisons with existing lossy compression algorithms is studied. In our experiments, the proposed algorithm is tested on MATLAB 7.14 with a computer of Intel (R) Core (TM) i3-2100 3.10GHz CPU, 2GB memory. The standard test color images (24bits/pixel, 512×512) we used are Lena, Peppers, Mandrill, and Airplane, shown in Fig. 8. We have applied the improved luminance quantization table to JPEG-like compression algorithm based on APWBT, APDCBT and APIDCBT. To evaluate the quality of interpolated images, CPSNR and subjective visual assessment are chosen to measure the performance of different methods. We compare the proposed algorithm with Wang [3] and baseline JPEG based on DCT.

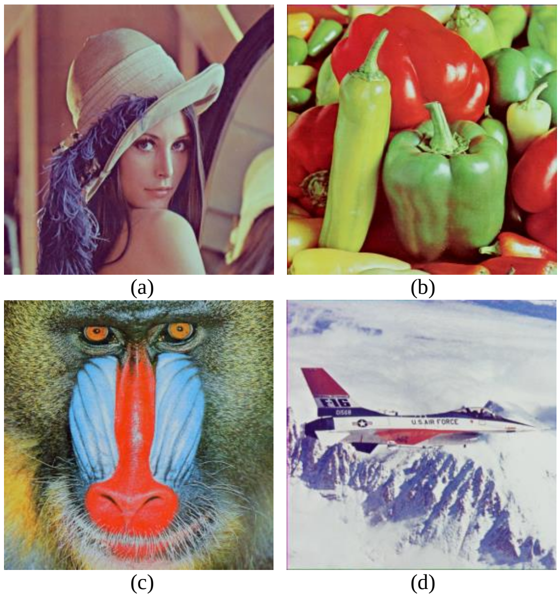


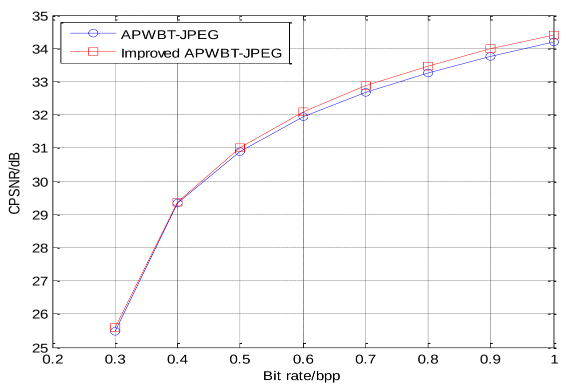
Fig. 8. The standard test color images: (a) Lena, (b) Peppers, (c) Mandrill, and (d) Airplane.

A. *Objective Performance Evaluation*

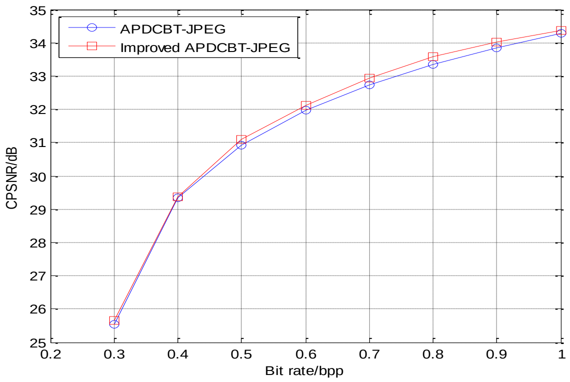
CPSNR is the most popular, the most widely used method of measuring objective evaluation quality, as defined in (12).

$$\mathrm{CPSNR} = 10\log_{10}\left[\frac{255^2}{\frac{1}{3MN}\sum_{k=1}^{3}\sum_{i=1}^{M}\sum_{j=1}^{N}[I_{\mathrm{in}}(i,j,k) - I_{\mathrm{out}}(i,j,k)]^2}\right] (\mathrm{dB}) \quad (12)$$

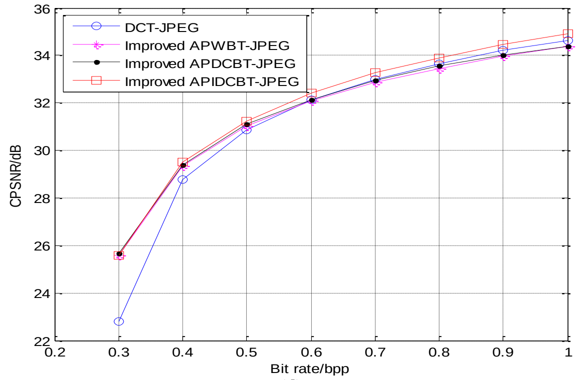
where M and N indicate the length and width of the image, respectively. I_{in} is the original input image. I_{out} is the output image. In this paper, CPSNR is adopted as objective evaluation criteria of color image compression algorithms. Table I depicts the experimental results of comparisons among DCT-JPEG, APBT-JPEG of Wang [3], and improved APBT-JPEG scheme applied to color image Lena. Notice that our algorithm could obtain better performance than Wang's no matter using APWBT, APDCBT, and APIDCBT. Moreover, our algorithm based on APIDCBT outperforms DCT-JPEG at all bit rates.



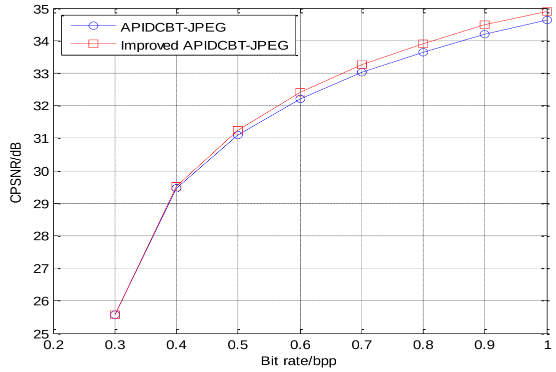
(a)



(b)



(d)



(c)

Fig. 9. Rate-distortion curves of different color image compression algorithms: (a) APWBT-JPEG and improved APWBT-JPEG, (b) APDCBT-JPEG and improved APDCBT-JPEG, (c) APIDCBT-JPEG and improved APIDCBT-JPEG, and (d) DCT-JPEG and improved APBT-JPEG.

More tellingly, Fig. 9 gives the rate-distortion behavior obtained by applying various compression schemes on color image Lena. It is clearly seen that our progressive APBT-JPEG outperforms by far by all other schemes, especially at low bit rates. In brief, for low quality imaging applications (i.e. 0.30~0.50bpp), our algorithm is 0.30~2.00dB better than DCT-JPEG and Wang's method.

TABLE I: CPSNR COMPARISONS OF DCT-JPEG, APBT-JPEG ALGORITHM OF WANG [3], AND IMPROVED APBT-JPEG SCHEME APPLIED TO COLOR IMAGE LENA

Bit rate (bpp)	CPSNR (dB)						
	DCT-JPEG	APWBT-JPEG		APDCBT-JPEG		APIDCBT-JPEG	
		Wang [3]	Proposed	Wang [3]	Proposed	Wang [3]	Proposed
0.30	22.79	25.48	**25.60**	25.54	**25.67**	25.56	**25.58**
0.40	28.79	29.34	**29.36**	29.34	**29.37**	29.47	**29.51**
0.50	30.87	30.90	**31.01**	30.93	**31.09**	31.11	**31.24**
0.60	32.14	31.93	**32.08**	31.97	**32.12**	32.21	**32.41**
0.70	33.01	32.68	**32.88**	32.73	**32.95**	33.02	**33.27**
0.80	33.66	33.27	**33.46**	33.34	**33.57**	33.65	**33.91**
0.90	34.20	33.76	**33.99**	33.84	**34.02**	34.19	**34.48**
1.00	34.63	34.19	**34.39**	34.29	**34.38**	34.63	**34.90**

B. Subjective Performance Evaluation

In image compression, the Block-Based DCT (BDCT) suffers from visible blocking artifacts between adjacent image blocks at low bit rates, which reduces the image visual quality. What are shown in Fig. 10, Fig. 11 are results of our improved compression algorithm applied to color image Lena at 0.40bpp and 0.70bpp, respectively. Note that in both of these two bit rates, the proposed algorithm based on APIDCBT outperforms the baseline JPEG based on DCT. Especially at low bit rate 0.40bpp, blocking artifacts have been removed significantly. By this way, not only the disturbed "blocking effects" which always lies in conventional DCT algorithm can be reduced, but also the coding performance can be increased without losing much coding quality as well.

C. Application of the Proposed Compression Algorithm Using Adaptive Interpolation in CFA

In this part, we firstly introduce the adaptive interpolation method of Zhou [16]. Their proposed method yields visually pleasant results and outperforms existing demosaicking methods in CPSNR. In addition, the computational complexity of the proposed method is comparable to the existing methods. Fig. 12 only gives an example for the test image Lena without JPEG compression. In further experiments, we combine this interpolation method with our improved compression algorithm to make performance verification preliminarily.


(a) (b)

Fig. 10. Lena obtained at 0.40bpp: (a) DCT-JPEG, CPSNR=28.79dB, and (b) Improved APIDCBT-JPEG, CPSNR=29.51dB.

Fig. 11. Lena obtained at 0.70bpp: (a) DCT-JPEG, CPSNR=33.01dB, and (b) Improved APIDCBT-JPEG, CPSNR=33.27dB.

Fig. 12. Example of adaptive interpolation of Zhou [16] for the test image Lena without JPEG compression.

TABLE II: CPSNR COMPARISONS OF COMPRESSION ALGORITHMS WITH AND WITHOUT INTERPOLATION APPLIED TO CFA IMAGE LENA

Methods			**CPSNR (dB)**
Without Interpolation	DCT-JPEG		33.01
	APWBT-JPEG	Wang [3]	32.68
		Proposed	32.88
	APDCBT-JPEG	Wang [3]	32.73
		Proposed	32.95
	APIDCBT-JPEG	Wang [3]	33.02
		Proposed	33.27
With Interpolation [16]	DCT-JPEG		31.91
	APIDCBT-JPEG		32.62
	Proposed APIDCBT-JPEG		32.74

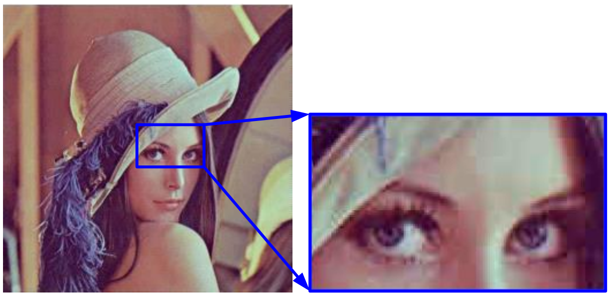


Fig. 13. Shown in the left is the obtained Lena with interpolation method of Zhou [16] based on DCT-JPEG at 0.70bpp, CPSNR=31.91dB, and shown in the right is the local image of magnification.

The diagram of CFA image compression algorithm based on our APBT-JPEG has been given in Fig. 7. Table II gives comparison results with and without interpolation applied to CFA image Lena at 0.70bpp. As can be deduced from Table II, the downsampling and interpolation in the processing of CFA compression algorithm cause the image quality degradation inevitably. In the CFA compression application, it is seen that our algorithm performs equivalently to DCT-JPEG in the case of the natural image Lena, with effectively removing blocking artifacts. In general, the proposed algorithm offers better performance in a very efficient way. Fig. 13, Fig. 14 show the obtained Lena images with interpolation method of Zhou [16] based on DCT-JPEG and improved APIDCBT-JPEG, respectively. The local images of magnification provide a way to intuitively understand for us.

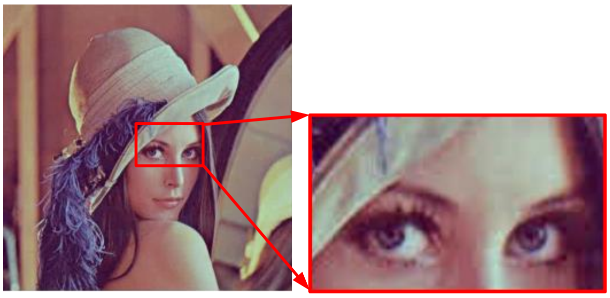


Fig. 14. Shown in the left is the obtained Lena with interpolation method of Zhou [16] based on improved APIDCBT-JPEG at 0.70bpp, CPSNR=32.74dB, and shown in the right is the local image of magnification.

Finally, we would like to point out that the proposed scheme is also applied to other test images: Peppers, Mandrill, and Airplane, and similar results can be obtained.

V. CONCLUSIONS

In this paper, we propose an improved luminance quantization table obtained by nonlinear programming method, which improves image quality obviously with the slightest increase of computational complexity. For chrominance quantization table, we adopt uniform quantization step according to HVS and the properties of APBT. Experimental results show that better performance has been obtained and blocking artifacts also have been removed partially. Besides, we also apply our color image compression algorithm to CFA image compression. Similar results have been obtained.

For further work, we can apply our improved algorithm to other applications in view of the better coding and high frequency attenuation properties. We will also adopt all phase DCT interpolation [17] in optimizing its implementation performance.

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