# Bayer Patterned Image Compression Based on Structure Conversion and APBT

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## *Abstract*

*The color filter array (CFA) captures only one-third of the necessary color intensities and the full color image is generated from the captured data by interpolation. In recent years, the algorithm of Bayer patterned image compression based on "structure conversion" has achieved better image quality. On the basis of previous work, a new algorithm based on the all phase biorthogonal transform (APBT) and all phase IDCT (APIDCT) interpolation is proposed in this paper. Instead of the conventional JPEG compression, APBT is applied to the JPEG image compression (APBT-JPEG), which significantly reduces complex multiplications and makes the quantization table easier. In the interpolation step, APIDCT interpolation method is introduced. Experimental results show that the proposed algorithm outperforms the one based on "structure conversion"; and the APIDCT interpolation performs close to the conventional interpolation methods. Therefore, the algorithm proposed in this paper is more suitable for Bayer image compression.*

*Keywords: Image Compression, All Phase Biorthogonal Transform (APBT), Structure Conversion, Color Filter Array (CFA)*

## 1. Introduction

From a color filter array (CFA), digital cameras obtain the color image information. However, only one color component is retained at each pixel location. To recover the full color image, interpolation is applied to the decompressed image. In various structures of CFA, Bayer pattern is the most widely used, as shown in Figure 1 [1]. It can be seen that the number of green (G) component is twice than the red (R) or blue (B) component, which is more suitable for the color sensitivity of human eyes.
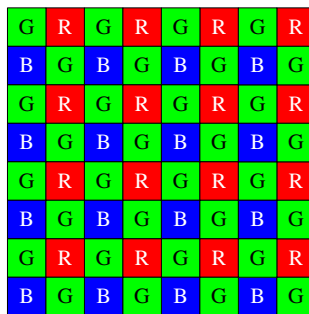


**Figure 1. Bayer patterned CFA structure**

Since each pixel and its adjacent pixels in space are not continuous for Bayer image, the high frequency component is large between the adjacent components. Direct compression to the Bayer image does not make for improving the compression ration. Therefore, various compression algorithms for Bayer image have appeared. Lee [2] proposed "geometric rotation" compression method, and the image data is firstly converted from RGB color space to YCbCr color space. The Cb, Cr components are equivalent to a 4:2:0 sampling operation, while Y component needs to be converted into rhombus with a $45^{\circ}$ rotation. In recent years, Koh [3] proposed two new lossy compression algorithms, referred to as "structure conversion" and "structure separation", which have achieved better results. On this basis, Xie [4] improved the structure conversion algorithm. In addition, there are lots of algorithms for original data compression [5-7]. However, all these algorithms used discrete cosine transform (DCT) in compression step, which brought more complex quantization table and serious blocking artifacts at low bit rates.

To solve these problems, Ref. [8] proposed the new concept of the all phase biorthogonal transform (APBT), which had been successfully applied to JPEG image compression (APBT-JPEG). On the basis of APBT theory, a novel Bayer patterned image compression algorithm based on APBT-JPEG and all phase IDCT (APIDCT) interpolation is proposed in this paper. In the compression step, APBT is adopted instead of the conventional DCT, and the uniform quantization table is used instead of the complex quantization Table, which makes the computation complexity reduced and the hardware easier implemented. Besides, a novel interpolation method of APIDCT [9] is used to the depressed image data. Experimental results show the algorithm proposed in this paper performs better than the conventional algorithms.

The rest of this paper is organized as follows. Section 2 introduces the structure conversion algorithm for Bayer patterned image. In Section 3, the Bayer image compression algorithm based on structure conversion and APBT is presented. In Section 4, experimental results and comparisons with conventional algorithms are presented. Finally, conclusions and remarks on further research are given in Section 5.

## 2. Structure Conversion Algorithm for Bayer Patterned Image

The scheme of the improved structure conversion algorithm in [3] is shown in Figure 2. First, the structure conversion is applied to G component, and then data in RGB color space are converted to YCbCr color space, because the correlation between pixels in RGB color space is higher than that in YCbCr color space. Due to the original rectangular distribution of R and B components, the loose rectangle only needs to become compact rectangle without low-pass filtering and structure conversion.
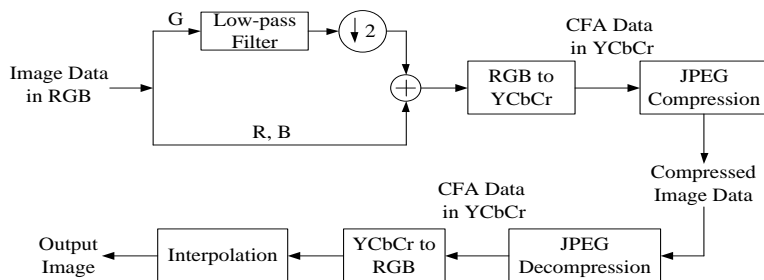


**Figure 2. Scheme of Structure Conversion Algorithm**

## 2.1. Color Space Conversion

The original Bayer image can be seen as a set composed of GB/RG blocks with size of $2 \times 2$. Using the similarity between pixels, R, G and B components can be converted to luminance and chrominance values in YCbCr color space by transform matrix, as shown in Figure 3. The Cb and Cr components are equivalent to a 4:2:0 sampling operation. The color space transform matrix is:

$$\begin{bmatrix} Y^{ul} \\ Y^{lr} \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 128.6 & 0 & 25 & 65.5 \\ 0 & 128.6 & 25 & 65.5 \\ -37.1 & -37.1 & 112 & -37.8 \\ -46.9 & -46.9 & -18.2 & 112 \end{bmatrix} \begin{bmatrix} G^{ul} \\ G^{lr} \\ B \\ R \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 128 \\ 128 \end{bmatrix} \tag{1}$$

where $^{ul}$ represents upper left corner, while $^{lr}$ represents lower right corner.
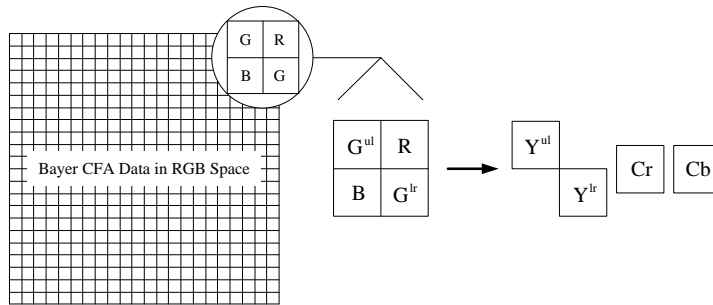


**Figure 3. Blocks of Color Space Conversion**

## 2.2. Structure Conversion

The structure conversion of G component is shown in Figure 4, where Go, Ge and Gc are odd, even, and converted columns respectively. Since the G component is quincuncial, it needs to become a rectangle. Directly emerging odd and even columns will produce a lot of pseudo-high-frequency components, in order to suppress the generation of pseudo-high-frequency components, G component needs a smoothing processing, which can be divided into two steps: low-pass filter and 2:1 sampling of columns. The impulse response function of the low-pass filter is:

$$h_d[m,n] = \frac{1}{4}\begin{bmatrix} 0 & 0 & 1 \\ 0 & 2 & 4 \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

After the sampling of columns, G component becomes a rectangle, of which the number of rows is equal to the original image and the number of columns becomes a half of the original number of columns.

The image data achieved after structure conversion and color space conversion is compressed by the still image compression standard JPEG. After the storage or transmission, the compressed image is decompressed to recover the CFA data, of which the steps are opposite to ones described earlier. After decompression, there is no need to add the inverse transform of the filtering, because the correlation between pixels has been weak after a previous process. This not only makes the decompression algorithm easier, but also achieves better results through the practical test.
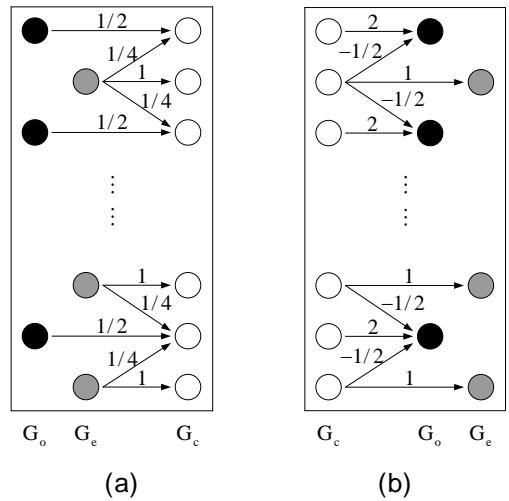
Figure 4. Structure Conversion

## 3. Bayer Patterned Image Compression Based on Structure Conversion and APBT

The process of the new algorithm proposed in this paper is shown in Figure 5. Wherein, the steps of structure conversion and color space conversion are same as ones of the structure conversion algorithm for original Bayer image, while the second half of the algorithm is image compression based on APBT instead of the JPEG compression in the conventional algorithm. Meanwhile, APIDCT interpolation is applied to the reconstructed CFA data to recover the full color image.
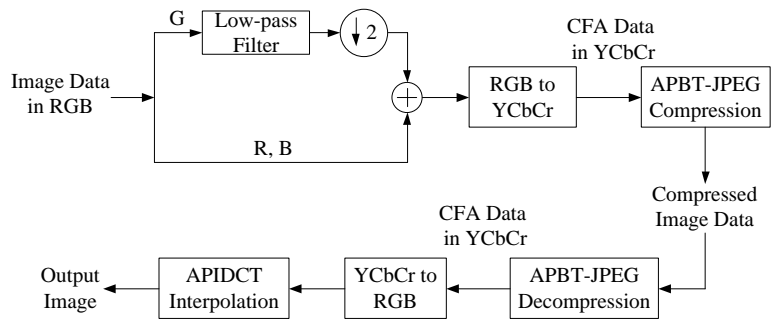


Figure 5. Scheme of Bayer Patterned Image Compression based on Structure Conversion and APBT

### 3.1. APBT-JPEG Compression Algorithm

Figure 6 shows the APBT-JPEG compression algorithm. Substantially the same as basic steps of the DCT-based JPEG image compression algorithm, but the APBT replaces the conventional DCT and the simple uniform quantization step is applied instead of the complex quantization table. Based on different orthogonal transforms: Walsh-Hadamard, DCT and IDCT, three kinds of all phase biorthogonal transform (APBT) were presented, referred to as all phase Walsh biorthogonal transform (APWBT), all phase discrete cosine biorthogonal transform (APDCBT) and all phase inverse discrete cosine biorthogonal transform (APIDCBT).
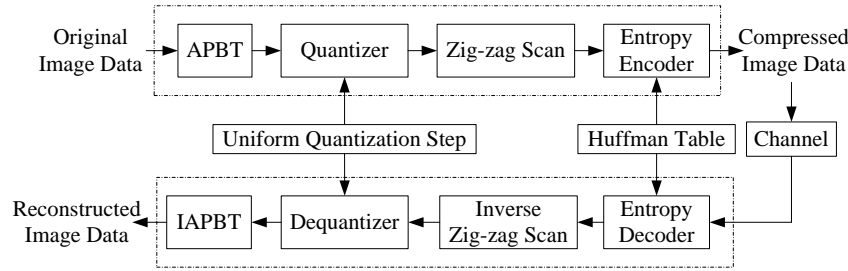
**Figure 6. Diagram of the APBT-JPEG Compression Algorithm**

### 3.2. Design of All Phase IDCT Interpolation

Based on the all phase filtering theory [10], the APIDCT filter is proposed in [9]. Let $h_{(2N-1)\times(2N-1)}$ denote the 2-D unit impulse response of the all phase sequency filtering, and $F_{N\times N}$ denote the sequency response vector of length $N$. Therefore, the design of 2-D APIDCT filter with size of $(2N-1)\times(2N-1)$ is composed of (3) and (4)

$$\left[h_{1/4}\right]_{N\times N} = VF_{N\times N}V^{\mathrm{T}}, \tag{3}$$

$$h(m,n) = h(-m,n) = h(m,-n) = h(-m,-n),\ m,n = 0,1,\cdots,N-1, \tag{4}$$

where $V$ denotes the APIDCBT matrix [8], and has the form

$$V(m,n) = \begin{cases} \dfrac{1}{N}, & m=0, n=0,1,\cdots,N-1, \\ \dfrac{N-m+\sqrt{2}-1}{N^2}\cos\dfrac{m(2n+1)\pi}{2N}, & m=1,2,\cdots,N-1, n=0,1,\cdots,N-1. \end{cases} \tag{5}$$

When $N=4$ and $N=2$, the APIDCT filters used in this paper are

$$h_{7\times7} = \begin{bmatrix} 0 & 0.01 & 0 & 0.01 & 0 & 0.01 & 0 \\ 0.01 & 0 & -0.06 & 0 & -0.06 & 0 & 0.01 \\ 0 & -0.06 & 0 & 0.34 & 0 & -0.06 & 0 \\ 0.01 & 0 & 0.34 & 1 & 0.34 & 0 & 0.01 \\ 0 & -0.06 & 0 & 0.34 & 0 & -0.06 & 0 \\ 0.01 & 0 & -0.06 & 0 & -0.06 & 0 & 0.01 \\ 0 & 0.01 & 0 & 0.01 & 0 & 0.01 & 0 \end{bmatrix}, \tag{6}$$

and

$$h_{3\times3} = \begin{bmatrix} 0 & 0.25 & 0 \\ 0.25 & 1 & 0.25 \\ 0 & 0.25 & 0 \end{bmatrix}. \tag{7}$$

From (6) and (7), it can be seen that the sum of weight coefficients (except the center one) is 1 in each interpolation template and the value of the central symmetric weight coefficients is 0 alternately. In this paper, $h_{7\times7}$ is suitable for G component. When interpolating the R or B component, the APIDCT filters are $h'_{11\times11}$ and $h'_{3\times3}$, which can

be obtained by $h_{7\times7}$ and $h_{3\times3}$ rotating $45°$ respectively. Taking into account the characteristics of the data, the R or B component is firstly interpolated by the filter $h'_{11\times11}$, and then the filter $h'_{3\times3}$ is applied to the obtained data.

# 4. Experimental Results

This paper selects the image Lena with size of $512\times512$ for test, and the Bayer CFA data needed in the algorithm can be obtained by down-sampling the 24bits/pixel full color images. In the structure conversion algorithm, bilinear interpolation is adopted.

## 4.1. Comparison of CPSNR

To measure the performance of algorithm proposed in this paper, we choose the Composite Peak Signal to Noise Ratio (CPSNR) [11] defined as

$$\text{CPSNR}=10\log_{10}\left[\frac{255^2}{\frac{1}{3MN}\sum_{k=1}^{3}\sum_{i=1}^{M}\sum_{j=1}^{N}\left[I_{\text{in}}(i,j,k)-I_{\text{out}}(i,j,k)\right]^2}\right]\text{(dB)}, \tag{8}$$

where $I_{\text{in}}$ and $I_{\text{out}}$ are the original and reconstructed images respectively, $M$ and $N$ are the dimensions of each color component array, $i$ and $j$ are the locations of pixels in the color plane, and $k$ represents the color plane.

The comparison results of the objective quality of the two algorithms are shown in Table 1. From the data in the table, it can be seen that the proposed algorithm in this paper is better than the conventional structure conversion algorithm at various bit rates (0.2bpp~1.0bpp), in terms of CPSNR. Especially, for the Bayer images dominated by low-frequency components, the CPSNRs are improved more obviously.

**Table 1. Comparison of CPSNR at Various Bit Rates Applied to Lena**

| Bit rate/bpp | CPSNR/dB | |
|---|---|---|
| | Structure conversion | Proposed algorithm |
| 0.20 | 27.04 | 27.55 |
| 0.30 | 29.22 | 29.41 |
| 0.40 | 30.21 | 30.39 |
| 0.50 | 30.83 | 31.01 |
| 0.60 | 31.23 | 31.43 |
| 0.70 | 31.54 | 31.75 |
| 0.80 | 31.81 | 32.02 |
| 1.00 | 32.14 | 32.39 |

## 4.2. Comparison of Subjective Quality

Figure 7 gives the reconstructed images of Lena at 0.20bpp by using the structure conversion algorithm and the proposed algorithm in this paper. From the reconstructed images, we can see that the visual effect of the proposed algorithm is better than the conventional structure conversion algorithm. Further, the edge information of the image is clearer and easier to be accepted without blocking artifacts.

(a)                                    (b)

**Figure 7. The Reconstructed Images of Lena (0.20bpp): (a) Improved Structure Conversion, (b) Proposed Algorithm**

## 5. Conclusion

This paper presents a novel algorithm for Bayer image compression based on the structure conversion and APBT. From the simulation experiments, it can be concluded that the CPSNR of the proposed algorithm in this paper outperforms the conventional structure conversion algorithm, and better visual quality also has been achieved. Thus we can foresee that the proposed algorithm can be widely used in Bayer image compression.

## Acknowledgements

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