An Efficient Prediction Based Lossless Compression Scheme for Bayer CFA Images

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Abstract: Bayer color filter array (CFA) images are captured in most digital cameras and demosaicing is generally carried out before compression. A efficient prediction based lossless CFA compression scheme is proposed. It divides a CFA image into two sub images: a green sub image which contains all green samples of the CFA image and a non green sub image which holds the red and the blue samples. The green sub image is coded first and the non green sub image follows based on the green sub image as a reference. To reduce the spectral redundancy, the non-green sub image is processed in the color difference domain whereas the green sub image is processed in the intensity domain as a reference for the color difference content of the non green sub image. Both sub images are processed in raster scan sequence with prediction technique to remove the spatial dependency. The prediction residue planes of the two sub images are then entropy encoded sequentially with scheme of adaptive Rice code. Simulation results show that the proposed compression scheme can achieve a better compression performance than conventional lossless CFA image coding schemes.

Keywords: about four key words separated by commas.

1. INTRODUCTION

Cost effective digital cameras use image sensors that sample only one of the three primary colors at each pixel position. They use a single-image sensor, applying alternating patterns of red, green and blue color filters to each pixel location. Each pixel is covered with a filter and records just one of the three primary colors red, green or blue. These primary color samples are interleaved in a two-dimensional (2-D) grid, or color mosaic, resembling a three-color checkerboard. A Bayer color filter array (CFA) [1]-[2], as shown in Fig. 1, is usually coated over the sensor in these cameras to record only one of the three color components at each pixel location. The resultant image is referred to as a CFA image. In general, a CFA image is first interpolated via a demosaicing process [3]-[7] to form a full color image before being compressed for storage. The problem of reconstructing a full three-color representation of color images by estimating the missing pixel components in each color plane is called demosaicing. The image quality of digital cameras largely depends on the performance of the color demosaicing process.

Fig. 1. Bayer pattern having a red sample as its center. Recently, some reports [8]-[11] indicated that such a demosaicing-first processing sequence was inefficient in a way that the demosaicing process always introduced some redundancy which should eventually be removed in the following compression step. As a result, an alternative processing sequence [8]-[11] which carries out compression before demosaicing has been proposed lately. Under this new strategy, digital cameras can have simpler design and lower power consumption as computationally heavy processes like demosaicing can be carried out in an offline powerful personal computer.

Drawbacks of the existing methods are
1. Lossy schemes compress a CFA image by discarding its visually redundant information.
2. These schemes usually yield a higher compression ratio as compared with the lossless schemes.
3. For high end photography applications this is not suitable method
4. Some lossless image compression schemes like JPEG-LS and JPEG2000 can be used to encode a CFA image but only a fair performance can be attained.

This motivates the demand of CFA image compression schemes. There are two categories of CFA image compression schemes: lossy and lossless. Lossy schemes compress a CFA image by discarding its visually redundant information. These schemes usually yield a higher compression ratio as compared with the lossless schemes. Schemes presented in [11]-[20] are some examples of this approach. In these schemes, different lossy compression techniques such as vector quantization [12], [13] sub band coding, transform followed by JPEG or JPEG 2000 [14]-[16], and low-pass filtering followed by JPEG-LS or JPEG 2000 are used to reduce data redundancy. In some high-end photography applications such as commercial poster production, original CFA images are required for producing high quality full color images directly. In such cases, lossless compression of
CFA images is necessary. Some lossless image compression schemes like JPEG-LS and JPEG2000 can be used to encode a CFA image but only a fair performance can be attained.

The proposed scheme based prediction technique is presented. It shows how to estimate a missing green sample in the nongreen sub image of a CFA image for extracting the color difference information when compressing the nongreen sub image. The prediction residue is adaptively encoded with Rice Code is provided.

Experimental results show that the proposed compression scheme can effectively and efficiently reduce the redundancy in both spatial and color spectral domains. As compared with the existing lossless CFA image coding schemes such as [10]–[12], the proposed scheme provides the best compression performance in our simulation study. The proposed method is presented in Section 2. Section 3 demonstrates some simulation results, and, finally, a conclusion is given in Section 4.

2. PROPOSED METHOD

It divides a CFA image into two sub images: a green sub image which contains all green samples of the CFA image and a nongreen sub image which holds the red and the blue samples. The green sub image is coded first and the nongreen sub image follows based on the green sub image as a reference. To reduce the spectral redundancy, then on green sub image is processed in the color difference domain whereas the green sub image is processed in the intensity domain as a reference for the color difference content of the nongreen sub image. Both sub images are processed in raster scan sequence with our proposed context matching based prediction technique to remove the spatial dependency. The prediction residue planes of the two sub images are then entropy encoded sequentially with proposed realization scheme of adaptive Rice code. Advantages of the proposed method are

1. We can reduce the spectral redundancy mean time we can get high quality image
2. Reducing the sensors in digital cameras from 3 to 1
3. Low complexity to design

Algorithm of the proposed method is given below

**Step 1:** In the encoding phase, a CFA image is first divided into a green sub image and a nongreen sub image.

**Step 2:** The green sub image is coded first and the nongreen sub image follows based on the green sub image as a reference. To code a sub image, the sub image is raster-scanned and each pixel is predicted with its four neighboring pixels by using the prediction scheme

**Step 3:** The prediction error of pixel in the CFA image is given by

\[ e(i,j) = g(i,j) - \hat{g}(i,j) \text{ if } (i,j) \text{ is in green sub image} \]
\[ e(i,j) = d(m,n) - \hat{d}(m,n) \text{ if } (m,n) \text{ is in non green sub image} \]

where \( g(i,j) \) and \( d(i,j) \) are, respectively, the real green sample value and the color difference value of pixel \((i,j)\) \( g'(i,j) \) and \( d'(i,j) \), respectively, represent the predicted green intensity value and the predicted color difference value of pixel \((i,j)\). The error residue \( e(i,j) \) is then mapped to a non-negative integer.

**Step 4:** The \( E(i,j) \)'s from the nongreen sub image are further decomposed into two residue sub planes. One carries \( E(i,j) \)'s originated from the red CFA samples while the other one carries those originated from the blue CFA samples.

**Step 5:** The two residue sub planes are then raster scanned and coded with Rice code as well. Their order of processing does not matter as there is no interdependency among these two residue sub planes. That they are separately handled is just because the Rice code can be made adaptive to their statistical properties in such an arrangement. For reference, the residue sub planes originated from the red, the green and the blue CFA samples are, respectively, referred to as \( ER \), \( EG \) and \( EB \).

**Step 6:** Rice code is employed to code because of its simplicity and high efficiency in handling exponentially distributed sources. When Rice code is used, each mapped residue is split into a quotient and a remainder, where parameter is a nonnegative integer. The quotient and the remainder are then saved for storage or transmission.

**Step 7:** The decoding process is just the reverse process of encoding. The green sub image is decoded first and then the nongreen sub image is decoded with the decoded green sub image as a reference. The original CFA image is then reconstructed by combining the two sub images.
2.1 Prediction on the Green Plane

The green plane is raster scanned during the prediction and all prediction errors are recorded, all processed green samples are known and can be exploited in the prediction of the pixels which have not yet been processed. Assume that we are now processing a particular green sample as \( g(i,j) \) shown in Fig. 3(a). The four nearest processed neighboring green samples of form a candidate set \( \Phi \).

The candidates are ranked by comparing their support regions with that of \( g(i,j) \). The support region of a green sample at position \( (p,q) \), \( \Phi_{(p,q)} \), is defined as shown in Fig. 4(a).

2.2 Prediction on the Nongreen Plane

The nongreen plane is processed after the green plane, all green samples in a CFA image are known and can be exploited when processing the nongreen plane, the color difference values of all processed nongreen samples in the CFA image should also be known and, hence, can be exploited when predicting the color difference of a particular nongreen sample. Let \( d(p,q) \) be the green-red (or green-blue) color difference value of a nongreen sample \( c(p,q) \).

For any nongreen sample \( c(i,j) \), its candidate set is \( \Phi \) and its support region is \( \Phi_{(i,j)} \). Figs. 3(b) and 4(b), show, respectively, the positions of the pixels involved in the definition of \( \Phi_{(i,j)} \) and \( S_{(i,j)} \). The prediction for a nongreen sample is carried out in the color difference domain. Specifically, the predicted color difference value of sample is given by

\[
d(i,j) = \text{round} \left\{ \sum_{k} w_k d(m_k,n_k) \right\}
\]

2.3 Adaptive color difference estimation

The proposed method is used for estimating the color difference value of a pixel without having a known green sample of the pixel. Let \( c(m,n) \) be the intensity value of the available color sample (either red or blue) at a nongreen sampling position \( (m,n) \). The green-red (green-blue) color difference of pixel, \( d(m,n) \), is obtained by

\[
d(m,n) = g^*(m,n) - c(m,n)
\]

where \( g^*(m,n) \) represents the estimated intensity value of the missing green component at position \( (m,n) \). In the proposed estimation, \( g^*(m,n) \) is adaptively determined according to the horizontal gradient and the vertical gradient at \( (m,n) \).

\[
g^*(m,n) = \text{round} \left\{ \frac{\text{grad}_x(m,n) + \text{grad}_y(m,n)}{2} \right\}
\]
where $\mathbf{Gv}$ and $\mathbf{GH}$ denote, respectively, the preliminary green estimates obtained by linearly interpolating the adjacent green samples horizontally and vertically.

$$G_H = \frac{g(m,n-1) + g(m,n+1)}{2}$$
$$G_V = \frac{g(m-1,n) + g(m+1,n)}{2}$$

The prediction error of pixel in the CFA image is given by

$$e(i,j) = g(i,j) - g'(i,j)$$

where $g(i,j)$ and $d(i,j)$ are, respectively, the real green sample value and the color difference value of pixel $(i,j)$ and $g'(i,j)$ and $d'(i,j)$, respectively, represent the predicted green intensity value and the predicted color difference value of pixel $(i,j)$. The error residue $e(i,j)$ is then mapped to a non-negative integer. The $E(i,j)$'s from the non-green sub image are further decomposed into two residue sub planes. One carries $E(i,j)$'s originated from the red CFA samples while the other one carries those originated from the blue CFA samples. The two residue sub planes are then raster scanned and coded with Rice code as well. Their order of processing does not matter as there is no interdependency among these two residue sub planes. That they are separately handled is just because the Rice code can be made adaptive to their statistical properties in such an arrangement. For reference, the residue sub planes originated from the red, the green and the blue CFA samples are, respectively, referred to as $E_R$, $E_G$ and $E_B$.

Rice code is employed to code because of its simplicity and high efficiency in handling exponentially distributed sources. When Rice code is used, each mapped residue is split into a quotient and a remainder, where parameter is a nonnegative integer. The quotient and the remainder are then saved for storage or transmission.

### 2.4 Rice Coding

Rice Coding (RC) codes sources, with minimal loss in efficiency. The main advantages of codes are that the encoding tables can be easily changed by changing a single integer parameter $k$, and that output codeword can be easily computed for the corresponding input symbols, so that no explicit tables are actually needed. That makes RC coders quite attractive for modern processors, for which computations are much faster than memory accesses.

**Encoding procedure is given below**

Rice coding is fairly straightforward. Given a bit length, $K$, compute the modulus, $M$ using the equation $M = 2^K$. Then do following for each symbol $(S)$:

1. Write out $S$ & $(M - 1)$ in binary.
2. Write out $S >> K$ in unary.

**Example:**

Encode the 8-bit value 18 (0b00010010) when $K = 4 (M = 16)$

1. $S & (M - 1) = 18 & (16 - 1) = 0b00010010 & 0b1111 = 0b0010$
2. $S >> K = 18 >> 4 = 0b00010010 >> 4 = 0b0001$ (10 in unary)

So the encoded value is 10010, saving 2 bits.

**Decoding procedure is given below**

Decoding isn’t any harder than encoding. As with encoding, given a bit length, $K$, Compute the modulus, $M$ using the equation $M = 2^K$. Then do following for each encoded symbol $(S)$:

1. Determine $Q$ by counting the number of 1s before the first 0.
2. Determine $R$ reading the next $K$ bits as a binary value.
3. Write out S as $Q \times M + R$.

### 3. RESULT AND DISCUSSION

Twenty-four 24-bit color images of size 512 768 each as shown in Fig. 6a were sub sampled according to the Bayer pattern to form a set of 8-bit testing CFA images. They were then directly coded by the proposed compression scheme for evaluation. Fig. 6b & 6c, 6d are green and non green direction map image, reconstructed image.
Fig. 7 shows compression rate and PSNR of CFA image at different \( \alpha \) values; Table 1 lists the quality measures of the CFA images. It clearly shows that the proposed scheme outperforms all other schemes in all testing images. These results demonstrate that the proposed compression scheme is robust to remove the CFA data dependency even though the image contains complicated structures.

**Table 1** Comparison of quality measures for different medical images

<table>
<thead>
<tr>
<th>Medical Images</th>
<th>Quality Measures</th>
<th>Weightening factor</th>
<th>( \alpha=1 )</th>
<th>( \alpha=2 )</th>
<th>( \alpha=3 )</th>
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</thead>
<tbody>
<tr>
<td>CT image</td>
<td>Green Bit Rate</td>
<td>2.23</td>
<td>2.27</td>
<td>2.73</td>
<td></td>
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<tr>
<td></td>
<td>Non Green Bit Rate</td>
<td>2.4</td>
<td>2.42</td>
<td>2.87</td>
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<td></td>
<td>Bit Rate</td>
<td>2.32</td>
<td>2.34</td>
<td>2.8</td>
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<tr>
<td></td>
<td>Compression rate</td>
<td>3.44</td>
<td>3.4</td>
<td>2.85</td>
<td></td>
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<tr>
<td></td>
<td>PSNR</td>
<td>21.14</td>
<td>21.1</td>
<td>20.36</td>
<td></td>
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<tr>
<td>MRI Image</td>
<td>Green Bit Rate</td>
<td>3.3</td>
<td>3.35</td>
<td>3.6</td>
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<tr>
<td></td>
<td>Non Green Bit Rate</td>
<td>4.66</td>
<td>4.63</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td>Compression rate</td>
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<td>2</td>
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<tr>
<td></td>
<td>PSNR</td>
<td>18.13</td>
<td>18.12</td>
<td>17.6</td>
<td></td>
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</tbody>
</table>

### 4. CONCLUSION

The proposed scheme separates a CFA image into a green sub image and a nongreen sub image and then encodes them separately with predictive coding. The prediction is carried out in the intensity domain for the green sub image while it is carried out in the color difference domain for the nongreen sub image. In both cases, a context matching technique is used to rank the neighboring pixels of a pixel for predicting the existing sample value of the pixel. The prediction residues originated from the red, the green, and the blue samples of the CFA images are then separately encoded. The value distribution of the prediction residue can be modeled as an exponential distribution, and, hence, the Rice code is used to encode the residues. We assume the prediction residue is a local variable and estimate the mean of its value distribution adaptively. The divisor used to generate the Rice code is then adjusted accordingly as to improve the efficiency of Rice code. Experimental results show that the proposed compression scheme can efficiently and effectively decorrelate the data dependency in both spatial and color spectral domains. Consequently, it provides the best average compression ratio as compared with the latest lossless Bayer image compression schemes.

### References


