Cost Effective Demosaicing Directly Producing YCbCr 4:2:0 Output

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Abstract

In order to reduce the hardware size and cost, many digital still cameras use a single sensor array equipped with a color filter array to capture any one of the three primary color components on each pixel location. Demosaicing process is used to reconstruct the RGB color image. Generally, conversion from RGB to YCbCr format is preferred for compressing the demosaiced images. But, most of the color interpolation techniques produce RGB output image. In this paper a novel effective edge preserving, edge directed inter-plane weighted interpolating technique directly producing YCbCr 4:2:0 image is proposed for color interpolation. Experimental results show that the proposed method performs much better than other latest techniques in terms of PSNR, at a notably low computational complexity.

Keywords: Interpolation, Demosaicing, YCbCr color model, Compression, CFA.

1. Introduction

Nowadays, embedded digital imaging devices have become popular and prevalent over the traditional film cameras. Low cost, low power consumption, miniaturization in size and high speed are demanded from these devices. A digital camera would need three separate sensors to completely capture the image. In a three-chip color camera, the light entering into the camera is split and projected on to each spectral sensor. Each sensor requires its proper driving electronics, and the sensors have to be registered precisely. These additional requirements add a large expense to the system. In order to reduce the hardware cost, many digital still cameras use a single mosaiced sensor array to capture any one of the three primary colors at each pixel location. A mosaiced sensor is a monolithic array of many sensors, in which each sensor is covered by an optical filter sensitive to a specified wavelength, arranged in a geometric pattern. Among the various suggested Color Filter Arrays (CFA), the Bayer CFA pattern [3] is the most prevalent one, which is designed according to luminance and chrominance level. Fig. 1 shows the Bayer color filter array pattern. As a result, the missed two colors at each pixel location have to be interpolated back to get a full color image. The process of interpolating the missing colors is called as demosaicing or color interpolation [1] [2]. Generally, RGB output images are resulted from most of the interpolation techniques [4]. For compressing the still and video demosaiced image, it is preferred to covert the RGB color space into YCbCr color space. Still image compression standards such as JPEG, JPEG2000 and video compression standards such as MPEG, H.26x use the YCbCr format for compression. Color channels can be coded independently without loss of efficiency in YCbCr color space. Green channel is more dominant component than red and blue in luminance (59%). Red and blue components are dominant contributors in

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Chrominance. Luminance is more sensitive than chrominance for the human visual system. So, the chrominance Cb and Cr channels can be down-sampled by a factor of two in both the horizontal and vertical directions without loss of perceived image quality. In YCbCr 4:2:0 format, for every 2x2 mosaiced sensor image, there is one Cb, one Cr and four Y samples. The proposed method is based on the framework introduced by Colin Doutre et al [5], in which, the demosaicing process generates a full green channel, and low-pass filtered, down-sampled red and blue channels. An accurate luminance channel can be constructed using the high frequency details of green channel. The low-pass red and blue samples were used to directly compute down-sampled chrominance components.

The paper is organized as follows. In section 2, various existing demosaicing techniques are discussed, section 3 presents the details of our adaptive weighted color demosaicing technique directly producing YCbCr 4:2:0 Output and section 4 presents the comparison of simulation results in terms of peak-signal-to-noise-ratio (PSNR). Finally, concluding remarks are made in section 5.

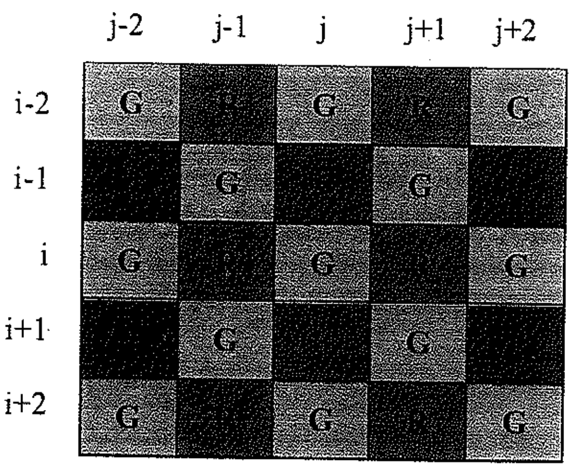

Figure 1: Bayer Color Filter Array Pattern

2. Existing Algorithms

The demosaicing algorithms can be classified as adaptive and non-adaptive algorithms. Non-adaptive algorithms perform interpolation in a fixed pattern for every pixel. While adaptive algorithms use both spectral and spatial features present in the pixel neighborhood, to interpolate the missed pixel as close to the original as possible. Like other color image processing problems, modeling the correlation among three color channels (planes) plays the critical role in demosaicing. All color channels have very similar characteristics such as texture and edge location. Ignoring such inter-plane dependency (e.g., straightforward intra-plane linear interpolation) often renders the demosaiced image suffering from annoying artifacts caused by incorrect interpolation.

To restore more accurate and visually pleasing results, many sophisticated demosaicing methods have been proposed by exploiting both spatial and spectral correlation of image [6]. Image spatial correlation refers the correlation between neighboring pixels color values on a plane. The spectral correlation refers the correlation between the red, green and blue image planes. Exploiting the spatial correlation means that the difference (or ratio) between two color planes is likely to be a constant within a local image neighborhood. Various techniques have been proposed to obtain a more faithful and higher quality reproduction of color images by exploiting the inter-plane correlation. Most of the non-adaptive color interpolation algorithms are done by averaging neighboring pixels that results the zipper artifact in the interpolated image. Adaptive algorithms are exploiting both spatial and spectral correlations effectively for choosing the best value for the missed color component on a pixel location, which results in reduction or elimination of zipper-type artifacts [8]. Edge sensing interpolations, Iterative interpolation, Gradients based interpolation, Pattern recognition interpolation, Pattern matching interpolation, Weighted average edge-directed interpolation, Adaptive color plane interpolation [9], Interpolation using variance of color differences, Iterative interpolation using weighted edge are examples of adaptive interpolation algorithms. All interpolation schemes reported above produce RGB output images. Most of the commonly used still image and video compression standards use YCbCr 4:2:0 color space for compression of information. Hence conversion from RGB to YCbCr color space is required for compressing the image. The proposed method directly produces YCbCr 4:2:0 outputs, at notably low complexity. Usually the mosaiced image is interpolated in RGB at first, converted into YCbCr and then low pass downsampling is carried out to get YCbCr 4:2:0 outputs. Following equations (1) are used for converting from RGB to YCbCr format [5].

$$Cb = -0.1687\,R - 0.3313\,G + 0.5\,B$$
$$Cr = 0.5\,R - 0.4187\,G - 0.0813\,B$$
$$Y = 0.299\,R + 0.587\,G + 0.114\,B \qquad (1)$$

The equations (2) are used for converting from YCbCr to RGB [5].

$$R = Y + 1.402\,Cr$$
$$G = Y - 0.34414\,Cb - 0.71414\,Cr$$
$$B = Y + 1.772\,Cb \qquad (2)$$

Among the different methods proposed in [10], YUV through green interpolation with median filtering post-processing (YUVGM) is the most competitive method. Colin Doutre et al proposed a method for directly producing YCbCr 4:2:0 outputs, in which following steps are carried out.

1. Interpolation of full green channel using the verticaland horizontal gradients
2. Calculation of low-pass red and blue samples
3. Calculation of down sampled chrominance channels Cb and Cr
4. Calculation of full luminance channel

The proposed method also follows the same procedure in addition with the adaptive technique is used to reconstruct an accurate green channel because the green channel contains the high-frequency detail needed to construct an accurate luminance channel.

3. Proposed Interpolation Algorithm

To reconstruct a full-color image from CFA samples, the two missed color values at each pixel are to be estimated from neighboring CFA samples. The green plane is estimated first and the other color planes are estimated based on the interpolated value of the green plane. When the green plane is processed, for each missing green component in the CFA, the algorithm performs a gradient test, to identify edge direction and then carries an interpolation along the direction [11] of a smaller gradient to determine the missed green component. The parameters, horizontal gradient (L_R^H or L_B^H) and vertical gradient (L_R^V or L_B^V) are computed by the equations (3) and (4) to determine the edge direction.

$$L_R^H = |G_{i,j-1} - G_{i,j+1}| + |R^H|$$
$$L_B^H = |G_{i,j-1} - G_{i,j+1}| + |B^H| \qquad (3)$$
$$L_R^V = |G_{i-1,j} - G_{i+1,j}| + |R^V|$$
$$L_B^V = |G_{i-1,j} - G_{i+1,j}| + |B^V| \qquad (4)$$

where
$$R^H = 2\,R_{i,j} - R_{i,j-2} - R_{i,j+2}$$
$$R^V = 2\,R_{i,j} - R_{i-2,j} - R_{i+2,j}$$
$$B^H = 2\,B_{i,j} - B_{i,j-2} - B_{i,j+2}$$
$$B^V = 2\,B_{i,j} - B_{i-2,j} - B_{i+2,j}$$

For smooth block, the difference between horizontal and vertical gradient of the block should be very low.

3.1 Interpolation of Green Plane

To construct an accurate luminance channel, the high-frequency details of green channel being needed. Therefore, the missing green pixels are estimated by exploiting both spatial and spectral correlation effectively.

The missing green pixels on red location can be interpolated as in (5).

$$\text{If } L_R^V > 1.5\, L_R^H$$
$$G_{i,j} = (W(G^H + R^H/2) + (1-W)(G^V + R^V/2))/2$$
$$\text{If } L_R^H > 1.5\, L_R^V$$
$$G_{i,j} = (W(G^V + R^V/2) + (1-W)(G^H + R^H/2))/2$$
$$\text{else}$$
$$G_{i,j} = ((G^V + R^V/2) + (G^H + R^H/2))/2$$
$$\text{end} \qquad (5)$$

The missing green pixels on blue location can be interpolated as in (6).

$$\text{If } L_B^V > 1.5\, L_B^H$$
$$G_{i,j} = (W(G^H + B^H/2) + (1-W)(G^V + B^V/2))/2$$
$$\text{If } L_B^H > 1.5\, L_B^V$$
$$G_{i,j} = (W(G^V + B^V/2) + (1-W)(G^H + B^H/2))/2$$
$$\text{else}$$
$$G_{i,j} = ((G^V + B^V/2) + (G^H + B^H/2))/2$$
$$\text{end} \qquad (6)$$

where

$G^H = G_{i,j-1} + G_{i,j+1}$ and $G^V = G_{i-1,j} + G_{i+1,j}$

The best weight value for natural scene images (test images) is found as W=0.87

3.2 Low-Pass Red and Blue Samples

To directly compute down-sampled chrominance components, the low-pass red and blue samples are estimated as in (7).

$$Rlp_{i,j} = (R_{i,j-1} + R_{i,j+1} - G^H + (R_{i-2,j-1} - G_{i-2,j-1} + R_{i-2,j+1} - G_{i-2,j+1} + R_{i+2,j-1} - G_{i+2,j-1} + R_{i+2,j+1} - G_{i+2,j+1})/2)/4$$
$$Blp_{i,j} = (B_{i-1,j} + B_{i+1,j} - G^V + (B_{i-1,j-2} - G_{i-1,j-2} + B_{i-1,j+2} - G_{i-1,j+2} + B_{i+1,j-2} - G_{i+1,j-2} + B_{i+1,j+2} - G_{i+1,j+2})/2)/4 \qquad (7)$$

3.3 Down-sampled Chrominance Channels

Chrominance channels can be calculated using low-pass, down-sampled red and blue channels as in (8).

$$Cb_{i,j} = -0.1687\, Rlp_{i,j} + 0.5\, Blp_{i,j}$$
$$Cr_{i,j} = 0.5\, Rlp_{i,j} - 0.0813\, Blp_{i,j}$$
$$Cb_{i,j+1} = (Cb_{i,j} + Cb_{i,j+2})/2$$
$$Cr_{i+1,j} = (Cr_{i,j} + Cr_{i+2,j})/2 \qquad (8)$$

3.4 Full Luminance Channels

On a 2 X 2 window as shown in Fig. 2, the luminance values are calculated by the known and estimated values of luminance and chrominance as in (9).

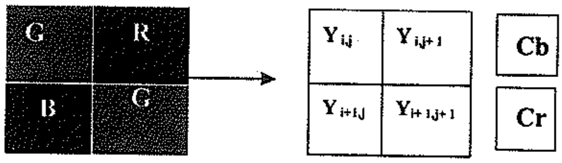

Figure 2: Conversion from mosaic 2 X 2 block to YCbCr 4:2:0 Samples

$$Y_{i,j} = 0.299\, Rlp_{i,j} + G_{i,j} + 0.114\, Blp_{i,j}$$
$$Y_{i,j+1} = 0.3375 R_{i,j+1} + 0.6625 G_{i,j+1} + 0.228 Cb_{i,j+1}$$
$$Y_{i+1,j} = 0.1626 B_{i+1,j} + 0.8374 G_{i+1,j} + 0.598 Cr_{i+1,j}$$
$$Y_{i+1,j+1} = 0.1785(Cr_{i,j} + Cr_{i+2,j} + Cr_{i,j+2} + Cr_{i+2,j+2}) + 0.086(Cb_{i,j} + Cb_{i+2,j} + Cb_{i,j+2} + Cb_{i+2,j+2}) \qquad (9)$$

4. Simulation Results

Twenty four 24-bit digital color images of size 512 X 768 pixels from Kodak color image database that include various scenes were used to generate a set of testing images. To evaluate the performance of this proposed color interpolation method, simulation was carried out and compared with other demosaicing techniques such as bilinear interpolation, adaptive color plane interpolation, effective color plane interpolation using signal correlation, demosaicing in YUV color space and fast demosaicing directly producing YCbCr output. Fig. 3 shows the tested images. The PSNR was used as a measure to quantify the performance of the demosaicing methods. Table 1 shows the comparison of different demosaicing algorithms with the proposed algorithm. The proposed method outperforms the other methods reported in [5] for most of the tested images in terms of PSNR. On average, the improvement over the existing best method [5] for chrominance is quite larger than for luminance.

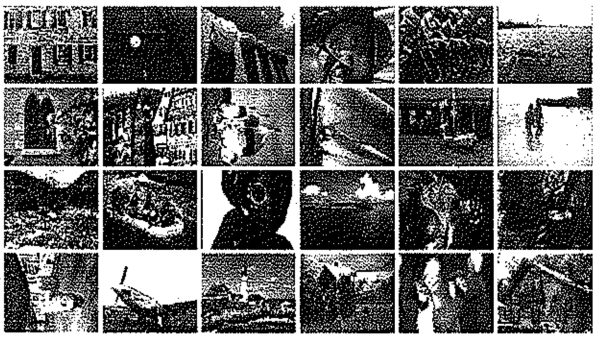

Figure 3: Tested Images (images are numbered from 1 to 24 in the order of left-to-right and top-to-bottom)

5. Conclusion

A novel highly edge preserving, adaptive weighted technique for color interpolation directly producing YCbCr 4:2:0 output formats for digital still cameras use a single sensor equipped with color filter array is presented. In the previous technique, the decision has been taken in accordance with the experimentally found hard threshold of 35 to provide good results for a wide range of images that results poor quality on edges. The above problem is solved by introducing the gradients relation and interpolation using both horizontal and vertical directions with appropriate weight for interpolation of the missing green sample in the proposed method. This technique is computationally efficient to produce the suitable format for compression by avoiding the need for demosaicing in RGB space and then converting from RGB to YCbCr 4:2:0. The image quality is also better than other demosaicing methods with lower computational complexity. Simulation results show that the proposed interpolation algorithm is able to produce subjectively and objectively better demosaicing results as compared with a number of existing algorithms.

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Table 1 : PSNR (in dB) Comparison

image	Bilinear			ACI [9]			ECI [6]			YUV [10]			AFD YCbCr [5]			Proposed		
	Y	Cb	Cr	Y	Cb	Cr	Y	Cb	Cr	Y	Cb	Cr	Y	Cb	Cr	Y	Cb	Cr
1	29.58	35.03	35.97	35.99	40.03	41.36	35.97	39.37	39.33	30.90	37.85	37.83	37.43	42.68	42.36	37.86	43.29	42.86
2	36.31	41.73	39.88	41.68	45.01	42.04	41.28	44.25	40.62	37.04	42.46	38.55	42.21	45.48	41.53	42.14	46.22	41.49
3	37.45	42.76	44.34	43.44	45.46	46.36	43.40	45.36	44.24	38.17	41.85	42.16	44.32	45.94	46.01	44.41	45.41	45.77
4	36.82	43.45	41.18	41.71	45.69	42.36	42.33	46.07	41.40	37.65	43.31	39.13	42.52	47.56	41.90	42.55	48.95	43.20
5	29.60	37.22	36.74	37.49	40.87	42.02	37.09	40.73	39.06	30.85	36.61	37.24	38.36	41.59	42.18	38.66	42.10	41.91
6	31.04	36.17	38.93	37.47	41.30	42.77	37.38	40.63	40.77	32.53	38.29	39.24	38.87	43.35	43.76	39.31	43.72	44.43
7	36.59	42.88	42.51	43.60	45.60	46.23	42.42	44.67	43.65	36.88	39.87	40.51	43.92	45.40	45.89	44.20	46.30	46.09
8	27.08	32.05	30.25	34.76	38.44	39.29	33.11	35.73	35.19	28.55	33.49	34.03	35.85	40.35	40.03	36.19	40.73	40.83
9	35.67	41.19	40.88	42.75	45.22	46.34	41.55	44.06	43.66	36.57	40.84	42.05	43.81	45.38	46.65	44.24	46.61	48.16
10	35.57	41.53	42.03	42.63	45.61	46.30	42.36	45.21	44.23	36.78	41.64	42.24	43.58	46.17	46.45	44.17	48.04	48.11
11	32.33	37.86	38.02	38.57	42.53	42.62	38.44	41.84	40.58	33.58	40.11	39.29	39.65	44.36	42.82	40.17	45.43	43.46
12	36.82	41.97	42.70	43.32	46.35	46.10	42.47	45.15	44.27	38.12	43.01	42.51	43.93	46.60	46.03	44.47	47.95	47.11
13	26.90	32.78	34.78	32.18	36.18	38.57	33.51	37.08	38.19	28.18	35.50	37.01	33.57	38.90	40.28	34.02	39.55	40.82
14	32.23	37.75	37.92	38.50	40.60	40.29	38.16	40.03	38.41	33.07	36.09	36.37	39.09	40.35	39.57	38.98	40.89	39.67
15	35.98	42.01	39.77	40.32	43.61	41.03	41.43	44.93	40.69	36.64	41.58	38.46	41.26	45.81	41.05	41.30	46.65	42.62
16	34.62	39.10	43.35	40.94	44.32	45.92	40.42	43.15	43.92	36.04	41.03	42.13	42.24	45.68	46.68	42.74	46.80	47.97
17	35.17	41.78	41.48	41.04	44.44	46.09	41.50	44.68	44.55	36.31	41.40	43.10	42.11	45.27	46.87	42.50	47.16	48.71
18	31.06	37.09	37.58	36.51	40.29	41.40	37.48	40.76	40.24	32.15	37.83	38.57	37.71	41.75	42.05	37.83	41.18	42.49
19	31.49	36.78	36.36	39.75	43.00	44.24	37.38	40.37	39.80	32.94	37.16	38.05	40.94	43.85	44.48	41.19	44.92	45.50
20	34.78	40.64	40.53	41.23	43.91	45.86	41.02	43.45	43.03	35.83	40.73	42.60	42.40	44.38	46.41	42.56	44.76	47.43
21	31.69	37.12	38.86	37.80	41.34	43.15	38.00	41.12	41.22	32.90	38.69	39.92	39.18	43.26	44.19	39.49	44.02	44.54
22	33.67	39.12	38.27	39.24	42.17	42.23	39.33	41.80	41.00	34.88	39.15	39.01	40.35	42.57	42.36	40.38	43.26	43.24
23	38.21	44.66	43.91	44.58	46.79	45.97	43.75	45.87	43.56	38.69	41.62	40.98	44.86	45.46	45.28	44.82	43.11	44.71
24	29.90	35.23	37.12	35.03	38.04	40.32	36.36	38.95	39.72	31.06	36.15	37.58	35.88	39.53	40.71	36.12	40.16	41.50
Ave	33.36	39.08	39.31	39.61	42.78	43.29	39.42	42.30	41.31	34.43	39.43	39.52	40.59	43.82	43.56	40.84	44.47	44.28

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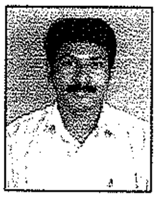

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