International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.6 (2016), pp.143-152
http://dx.doi.org/10.14257/ijmue.2016.11.6.13

Adaptive Camera Image Interpolation Method using Directional Color Plane Information

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Abstract

To reduce cost, current digital cameras adopt color filter array (CFA) instead of RGB camera which obtains beam splitters to capture image information. This leads effect that only one of three color channels remains and the other two color channels are missing during CFA. To compensate missing color information, color interpolation or demosaicking process is needed. There have been many methods with different degree of complexity and filter size. Normally bigger filters and higher complexity provide better performance. However, clever method may give fast and satisfactory results in terms of objective and subjective performance. This paper proposes adaptive camera image interpolation method which uses directional information. Simulation results show that the proposed method outperforms conventional benchmark method.

Keywords*: color image, color interpolation, upsampling quality assessment, quality enhancement*

1. Introduction

The multi-channel full color images are normally composed of three channels as cones of human eyes capture three colors [1-3]. Therefore, three difference image sensors are required to capture the intensity of each color [4]. Due to economical reason, most cameras use single sensor with color filter array (CFA) [5]. To reconstruct original image, color interpolation or demosaicking process is needed [6]. There are various CFA patterns in literature. However, currently Bayer pattern CFA is widely used [7-8].

The demosaicking methods can be classified into heuristic methods or non-heuristic methods [9-12]. Otherwise, demosaicking methods can be of directional information or non-directional information. Alternatively, some people can divide methods with spatial domain methods and frequency domain methods. In heuristic method category, ACPI (Adaptive Color Plane Interpolation) method is famous for its fast and good performance [13-18].

In general, conventional methods were based on heuristic approach. A method based on bilinear interpolation is assumed to be the straightforward method, where the missing channel information is restored on each color channel separately and high frequency information is not able to be well remain in the output result. By using inter-channel information (correlation), some methods were proposed to try to retain edge detail or restrict hue transitions to give better color interpolation result. For example, an ECI method is presented to obtain a full color image by reconstructing the color differences between G and R/B channels [15]. Based on ECI, some methods were presented recently. For example, a PCSD method eliminates color channel artifacts by pledging the same demosaicking direction for each color channel of a pixel [19]. In this paper, an adaptive camera image interpolation method using directional color plane information which tries to find correct edge direction is proposed.

ISSN: 1975-0080 IJMUE

The rest of the paper is organized as follows. Section 2 explains the proposed method. Section 3 describes experimental results where objective and subjective performance are assessed. Conclusion remarks are given in Section 4.

2. Proposed Method

Color images need multiple data channels for each pixel in contrast to grayscale images where a pixel is described by only one data sample (single channel data). For the RGB image representation, these data samples described with red, green and blue color channels. General digital camera obtains only one of three channels at each pixel position and the other two positions requested to be reconstructed to create the complete color information. This process is known as CFA interpolation.

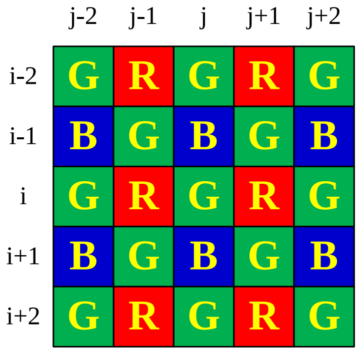


Figure 1. 5-By-5 Size Bayer Pattern CFA

In ACPI method, the green channel is restored first and then the other channels (red and blue) are reconstructed. The reason green channel is restored first is that green channel has twice more information as its sampling rate is twice than that of other two colors. When red or blue channel is restored, one may use restored green channel information. Figure 1 shows an example of 5-by-5 size Bayer pattern CFA. In this paper, horizontal and vertical gradients at (i,j) position, $H_{i,j}$ and $V_{i,j}$, are calculated as follows.

$$H_{i,j} = \left|G_{i,j-1} - G_{i,j+1}\right| + \left|R_{i,j-2} - 2R_{i,j} + R_{i,j+2}\right| \tag{1}$$

$$V_{i,j} = \left|G_{i-1,j} - G_{i+1,j}\right| + \left|R_{i-2,j} - 2R_{i,j} + R_{i+2,j}\right| \tag{2}$$

Where, $R_{i,j}$ and $G_{i,j}$ stand for the known red and green CFA information at location (i,j). Then, the missing green information, $mg_{i,j}$, is temporally obtained as follows.

$$mg_{i,j}^{case1} = \frac{G_{i,j-1} + G_{i,j+1}}{2} - \frac{R_{i,j-2} - 2R_{i,j} + R_{i,j+2}}{4} \tag{3}$$

$$mg_{i,j}^{case2} = \frac{G_{i-1,j} + G_{i+1,j}}{2} - \frac{R_{i-2,j} - 2R_{i,j} + R_{i+2,j}}{4} \tag{4}$$

$$mg_{i,j}^{case3} = \frac{G_{i,j-1} + G_{i,j+1}}{2} - \frac{R_{i,j-2} - 2R_{i,j} + R_{i,j+2}}{4} + \frac{G_{i-1,j} + G_{i+1,j}}{2} - \frac{R_{i-2,j} - 2R_{i,j} + R_{i+2,j}}{4} \tag{5}$$

There are three cases, *case*1, *case*2, and *case*3. Assume that the region is with *case*1 when $H_{i,j}$ is smaller than $V_{i,j}$. On the other hand, when $H_{i,j}$ is bigger than $V_{i,j}$, this region is determined as *case*2. Finally, a region is determined as *case*3 when $H_{i,j}$ and $V_{i,j}$ are identical. To improve correctness of the edge direction filter, parameters λ and γ, which control the weights between color channels, are added. Now, Equations (1) and (2) are amended as follows, where λ controls the system:

$$H_{i,j} = \left|G_{i,j-1} - G_{i,j+1}\right| + \lambda\left|R_{i,j-2} - 2R_{i,j} + R_{i,j+2}\right| \quad (6)$$

$$V_{i,j} = \left|G_{i-1,j} - G_{i+1,j}\right| + \lambda\left|R_{i-2,j} - 2R_{i,j} + R_{i+2,j}\right| \quad (7)$$

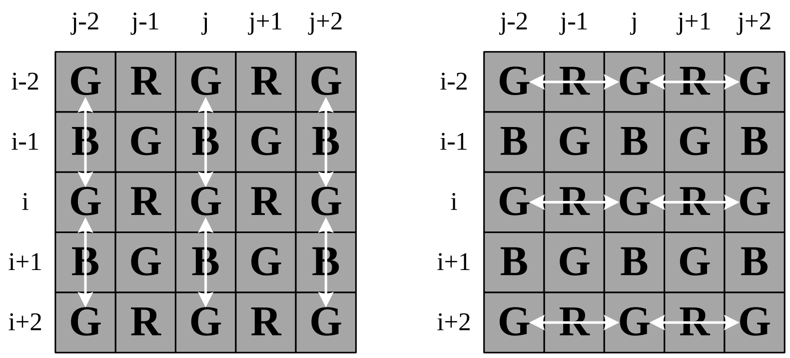
Similarly, Equations (3-5) are replaced by Equations (8-10), where γ controls the system.

$$mg_{i,j}^{case1} = \frac{G_{i,j-1} + G_{i,j+1}}{2} - \gamma\frac{R_{i,j-2} - 2R_{i,j} + R_{i,j+2}}{4} \quad (8)$$

$$mg_{i,j}^{case2} = \frac{G_{i-1,j} + G_{i+1,j}}{2} - \gamma\frac{R_{i-2,j} - 2R_{i,j} + R_{i+2,j}}{4} \quad (9)$$

$$mg_{i,j}^{case3} = \frac{G_{i,j-1} + G_{i,j+1}}{2} - \gamma\frac{R_{i,j-2} - 2R_{i,j} + R_{i,j+2}}{4} + \frac{G_{i-1,j} + G_{i+1,j}}{2} - \gamma\frac{R_{i-2,j} - 2R_{i,j} + R_{i+2,j}}{4} \quad (10)$$

One of important research directions is to exploit the correlation between the color channels, which lead better color interpolation performance. This paper proposes a better edge direction determination rule to achieve better performance. Figure 2 shows CFA for calculating weight of edge.



(a) (b)

Figure 2. Directional Information Calculation: (a) Horizontal, (b) Vertical

By using the filter to available green pixels, the edge directional information of the input image is obtained. It is noted that red or blue information was not considered to obtain edge information to meet coherence. Directional information will be assigned to the pixel to be interpolated which could be horizontal direction or vertical direction. The cost of horizontal direction and vertical direction are calculated through the process of Figure 2. Assume that the bigger cost may bring unwanted artifact, and therefore its direction should be given less weight.

The red and blue channel interpolation process is relatively simple. As the green channel is restored by the directional information, this information for computing red and blue channels can be used. For red color interpolation at blue position (or blue color interpolation at red position), pixels located in diagonal direction may be good candidates of being populated. In Equations (11) and (12), μ is the denominator to control the weight of R and G differences.

$$R_{i,j} = G_{i,j} + \frac{R_{i,j-1} - G_{i,j-1} + R_{i,j+1} - G_{i,j+1}}{\mu} \quad (11)$$

$$B_{i,j} = G_{i,j} + \frac{B_{i-1,j} - G_{i-1,j} + B_{i+1,j} - G_{i+1,j}}{\mu} \tag{12}$$

As a matter of fact that there is red and blue color channels located at green pixels, it is considering to another scenario. One of the simplest methods is to apply bilinear information. This paper applies the bi-cubic interpolation method in horizontal and vertical directions, and additionally, use nearest adjacent pixels and apply weighted average.

$$R_{i,j} = G_{i,j} + \frac{R_{i-1,j} - G_{i-1,j} + R_{i+1,j} - G_{i+1,j}}{\mu} \tag{13}$$

$$B_{i,j} = G_{i,j} + \frac{B_{i,j-1} - G_{i,j-1} + B_{i,j+1} - G_{i,j+1}}{\mu} \tag{14}$$

3. Experimental Results

The proposed method is tested on LC dataset. The test images are selected 25 images (#101-125) out of 150 images. Figure 3 shows 25 test images from LC dataset. All test images are primarily downsampled in Bayer CFA pattern and then demosaicked back to three color channels using color interpolation methods. All demosaicked images are compared to the original one and objective performance is assessed in CPSNR, S-CIELAB, and FSIM metrics. S-CIELAB represents a spatial extension to the CIELAB color metric for measuring color reproduction errors of digital images and FSIM is a feature similarity index for image quality assessment. The equation of CPSNR and CMSE are shown in Equations (15) and (16).

$$CPSNR = 20\log_{10}(255/\sqrt{CMSE}) \tag{15}$$

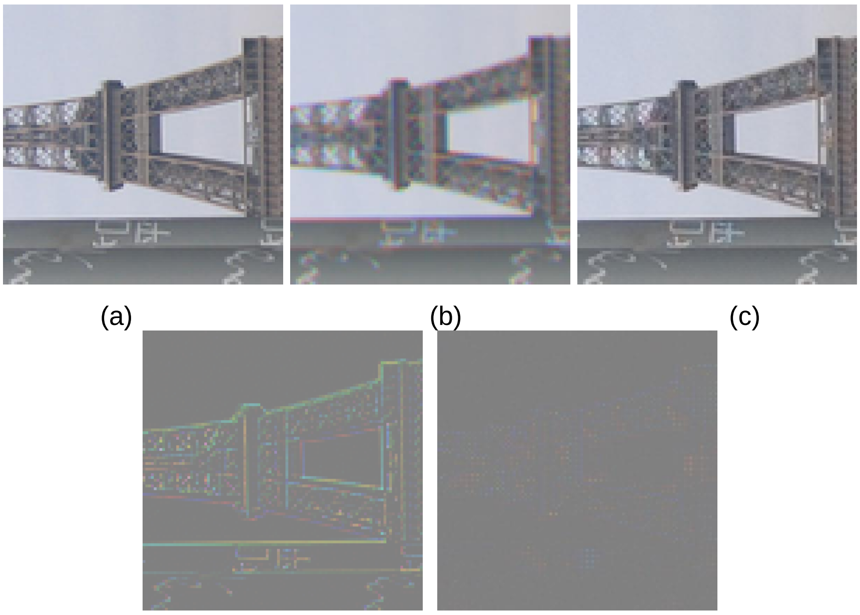
$$CMSE = \frac{1}{3HW} \sum_{i=\{R,G,B\}} \sum_{y=1}^{H} \sum_{x=1}^{V} \left[P(x,y,i) - Q(x,y,i) \right]^2 \tag{16}$$

Where, *P* and *Q* are original pixels and reconstructed pixels, respectively. It is noted that parameters *H* and *W* are original image size, height and width. Parameters λ, γ, and μ are determined as 1.2, 0.8, and 3.0, which were obtained empirically.

Figure 4 shows simulation results comparison using LC #101 image. As one can see, results from the proposed method well reconstructed image similar to the original one. However, bilinear interpolation result shows unwanted color artifacts, as shown in Figure 4(c). Similar results also can be found in Figure 5 and Figure 6.

Figure 5 shows results with LC #107 image. The original image has mosaic pattern, and high frequency components are in the image. Figure 5(b) shows bilinear interpolation result where false color is shown and the image is blurred. On the other hand, the proposed method shows favor result as shown in Figure 5(c). As can be seen in figures, the proposed approach achieved similar result with the original image, while bilinear interpolation result shows blurred image. In addition, various false colors are shown throughout the restored image. Figure 6 shows results from LC #113 image. It is obvious that bilinear interpolation results blur and orange false color artifacts. However, the proposed method did not reveal color errors.

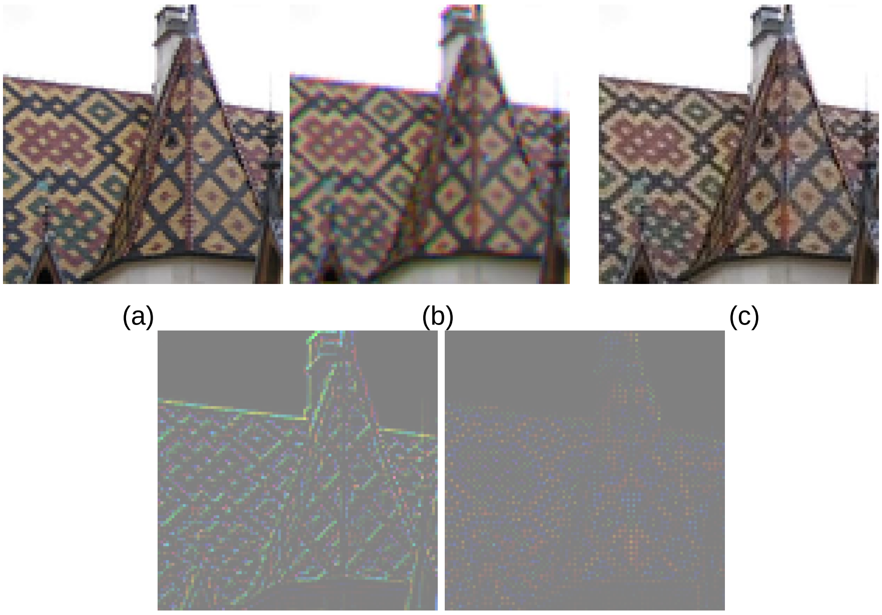
Figure 3. Test Images from LC Dataset



(a) (b) (c)

(d) (e)

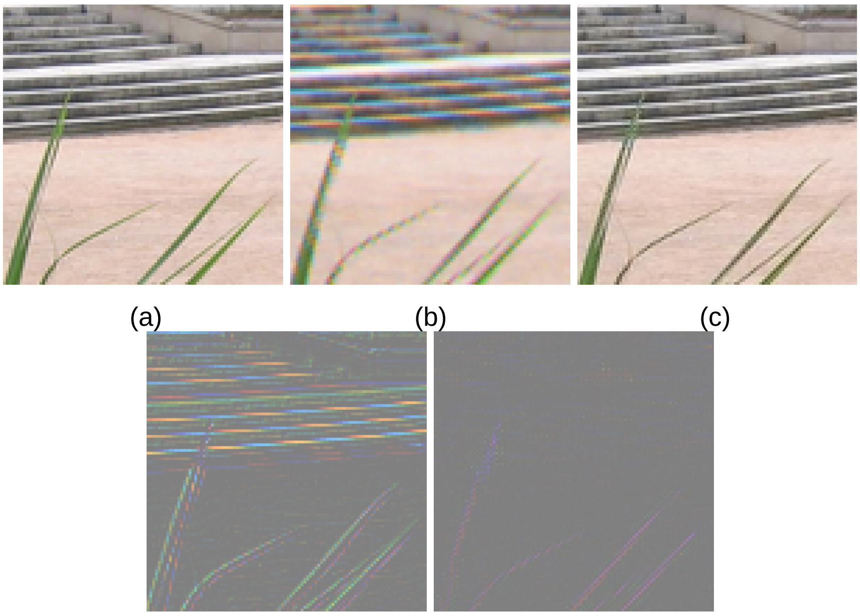
Figure 4. (a) Original Image of LC #101 Image, (b) Bilinear Interpolation, (c) Proposed Method, (d) Difference Between (a) and (b), and (e) Difference Between (a) and (c)



(a) (b) (c)

(d) (e)

Figure 5. (a) Original Image of LC #107 Image, (b) Bilinear Interpolation, (c) Proposed Method, (d) Difference Between (a) and (b), and (e) Difference Between (a) and (c)



(a) (b) (c)

(d) (e)

Figure 6. (a) Original Image of LC #113 Image, (b) Bilinear Interpolation, (c) Proposed Method, (d) Difference Between (a) and (b), and (e) Difference Between (a) and (c)

Figure 7 shows results from LC #116 image. The bilinear interpolation suppressed high frequency component, therefore result image looks like low pass filtered image. Figures 7(d) shows difference image between original and bilinear interpolation, and Figure 7(e) represents difference image between original and proposed method. Also, Figure 7(e) shows the least differences, which indicates the proposed method is quite identical to the original one.

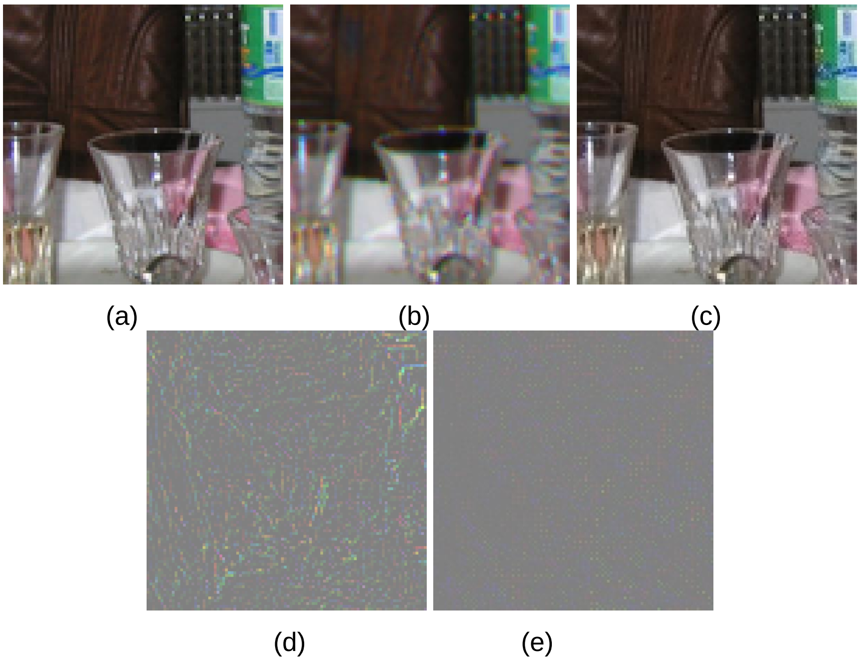


Figure 7. (a) Original Image of LC #116 Image, (b) Bilinear Interpolation, (c) Proposed Method, (d) Difference Between (a) and (b), and (e) Difference Between (a) and (c)

Table 1 shows objective performance comparison in three metrics: CPSNR, S-CIELAB and FSIM. The proposed method outperformed compared to conventional bilinear interpolation. Table 2 shows MSE results on three different channels. The proposed method achieved much better performance than that of bilinear interpolation.

Table 1. Objective Performance Comparison in Three Metrics

	CPSNR		S-CIELAB		FSIM	
image #	proposed	bilinear	proposed	bilinear	proposed	bilinear
1	39.864	31.653	0.718	2.087	0.998	0.977
2	37.911	29.210	0.988	3.071	0.998	0.972
3	34.932	28.887	1.183	2.461	0.997	0.976
4	31.687	23.387	2.069	5.533	0.996	0.936
5	32.750	24.529	1.549	5.300	0.997	0.963
6	32.604	29.862	1.820	3.002	0.996	0.974
7	34.535	27.455	1.306	3.272	0.997	0.962
8	29.701	23.856	2.396	5.472	0.995	0.957
9	34.586	28.128	1.399	2.901	0.996	0.968
10	33.804	24.585	1.547	4.140	0.997	0.962
11	33.700	25.483	1.894	4.647	0.997	0.961
12	36.603	27.537	1.119	3.283	0.998	0.970
13	30.922	24.767	2.141	4.845	0.996	0.955
14	35.693	28.753	1.337	2.748	0.997	0.970
15	28.076	25.282	2.163	3.579	0.989	0.958
16	34.580	28.798	1.234	2.929	0.997	0.974
17	32.715	26.381	1.935	3.748	0.996	0.964
18	32.323	24.834	1.778	4.573	0.996	0.961
19	35.692	32.044	0.661	1.673	0.997	0.976

20	35.269	28.388	1.274	3.060	0.997	0.974
21	33.483	24.812	1.877	4.531	0.997	0.964
22	32.220	27.768	1.510	2.967	0.996	0.970
23	32.362	30.890	1.536	2.622	0.997	0.985
24	33.557	31.096	1.481	2.915	0.997	0.980
25	31.826	26.788	2.601	4.697	0.996	0.967
Avg.	**33.655**	27.407	**1.581**	3.602	**0.996**	0.967

Table 2. MSE Results for Three Color Channels

	Red channel		Green channel		Blue channel	
image #	proposed	bilinear	proposed	bilinear	proposed	bilinear
1	6.789	44.671	3.787	52.386	9.552	36.279
2	10.373	69.080	6.497	102.536	14.685	62.388
3	19.961	82.853	13.302	98.571	29.400	70.636
4	42.900	269.770	24.178	395.338	65.204	229.265
5	27.800	192.451	17.218	285.064	58.548	209.965
6	31.759	54.525	22.646	82.379	52.689	64.480
7	24.006	112.558	12.379	150.137	32.280	87.833
8	76.952	237.455	38.742	304.899	93.292	260.377
9	25.036	112.292	13.411	110.098	29.414	77.776
10	24.785	224.884	17.578	251.837	38.891	202.094
11	22.576	170.616	18.852	222.994	41.783	158.308
12	11.800	105.215	9.968	143.295	20.882	95.432
13	58.571	223.515	35.976	248.311	63.207	179.024
14	18.553	85.605	10.131	115.145	23.902	59.183
15	126.737	148.682	46.929	223.511	130.148	205.909
16	26.195	73.891	11.683	99.084	30.069	84.308
17	31.879	143.106	24.916	187.999	47.598	117.698
18	39.686	211.375	23.911	239.533	50.657	190.056
19	29.841	39.508	8.844	53.378	13.922	28.944
20	18.684	92.095	12.591	107.281	26.703	83.381
21	26.804	213.794	19.307	223.939	41.369	206.455
22	39.164	99.864	24.248	118.145	53.586	108.161
23	57.644	62.813	25.666	51.832	29.927	44.292
24	24.771	25.107	16.556	80.445	44.682	46.016
25	36.339	117.272	24.803	165.439	66.973	126.008
Avg.	**34.384**	128.520	**19.364**	164.543	**44.374**	121.371

Results in Tables 1 and 2 are drawn in Figure 8. Images (a), (b), and (c) indicate CPSNR, S-CIELAB and FSIM, respectively. As one can see, the proposed method outperformed bilinear interpolation for whole tested images.

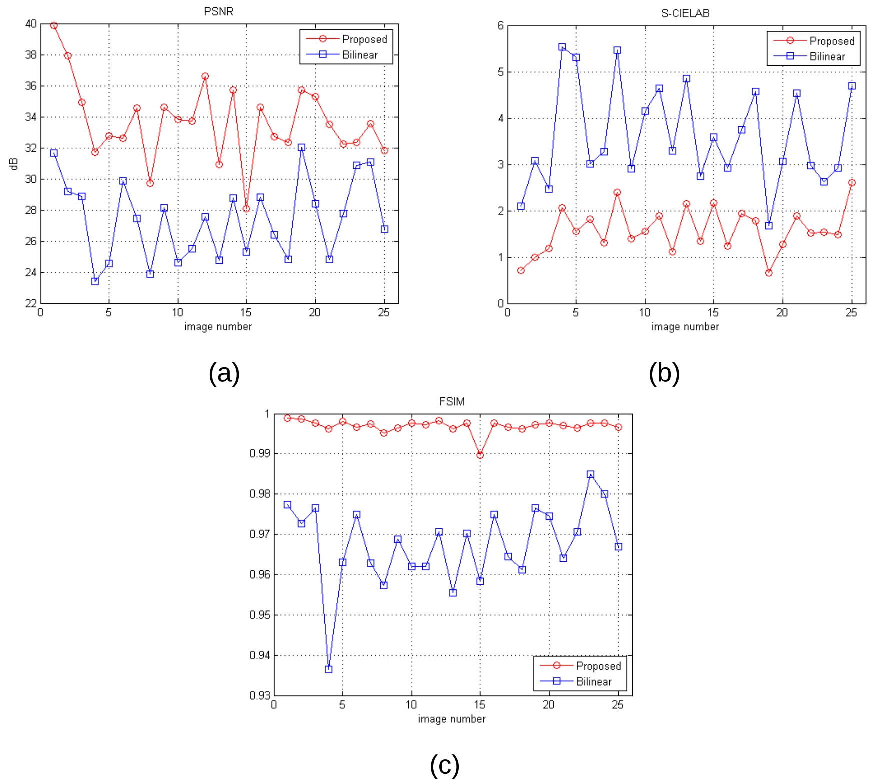


Figure 8. Objective Performance Comparison: (a) PSNR, (b) S-CIELAB, and (c) FSIM

4. Conclusions

For economical reason, most digital cameras uses color filter array instead of RGB camera. Although RGB camera provides more natural images, but its beam splitters for each pixel may cause high costs. Therefore, usage of CFA is inevitable and its color interpolation (demosaicking) is important topic. In this paper, an adaptive camera image interpolation method using directional color plane information is proposed. This method is based on well-known ACPI. By proposing a new edge direction determination rule, good restoration performance is achieved.

Acknowledgements

This research was supported by 2015-1 Hanyang Women's University Research Fund. This paper is a revised and expanded version of a paper entitled "Camera Image Interpolation using Directional Information" presented at GST2015.

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