EFFECTIVE COLOR INTERPOLATION IN CCD COLOR FILTER ARRAY USING SIGNAL CORRLEATION

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ABSTRACT

In this paper, we propose an effective color filter array interpolation method for digital still cameras using a simple image model that correlates the R, G, B channels. The main contribution of this paper is that we propose a low complexity interpolation method to improve the image quality. Simulation results verify that the proposed method obtain superior image quality. The G channel of the proposed method outperforms 6.34dB over bilinear method, and the R, B channels have 7.69dB improvement in average. Furthermore, the complexity of the proposed method is acceptable compared with the existing methods.

1. INTRODUCTION

Digital Still Cameras (DSCs) have been widely used as image input device. In order to reduce the cost the DSCs, digital camera designers use a single Charge-Coupled Device (CCD), instead of using three CCDs, with a Color Filter Array (CFA) to acquire color image [1]. Since there is only one color array element occupied in each pixel, the two missing color elements must be estimated from the adjacent pixels. This process is called CFA interpolation, or demosaicing. Bayer CFA pattern is the most frequently used CFA pattern. In this paper, we are focusing on the development of interpolation methods for Bayer CFA pattern.

Bilinear interpolation [2] is often used due to its simplicity. However, it induces large error in the edge region that blurs the resulting image. In order to improve the visual quality in the edge region, edge-sensing method [3] is introduced. Edge-sensing method interpolates the missing color elements according to the edge orientation of the image. However, only vertical and horizontal edges can be detected.

Since there is a high correlation between the R, G, B channels, interpolation method using color correlation is therefore expected to obtain better performance [4][5]. Based on this idea, we proposed an effective interpolation method using a simple image model, developed by J. E. Adams, Jr., [6], that correlates the R, G, B channels.

2. THE PROPOSED CFA INTERPOLATION METHOD

Since there is a high correlation between the R, G, B channels. It means that interpolation method of G channel can take advantage of the R, B information. To do this, we have to develop an image model about the correlation between the R, G, B channels. By using the image model developed by J. E. Adams, Jr. [6], we assume that R, B value are perfectly correlated to G value over the extent of the interpolation pixel neighborhood. Based on this model, we define K_R as green minus red and K_B as green minus blue, as shown in equation (1) and (2).

$$K_R = G - R \quad (1)$$

$$K_B = G - B \quad (2)$$

For real-world images, the contrasts of K_R and K_B are quite flat over small region and this property is suitable for interpolation. Fig. 1 illustrates an example of G channel image, quite flat K_R and K_B images. In other words, instead of performing the interpolation in the G domain, we simply transform the operation into K_R or K_B domains. Based on this transformation, we reduce the interpolation error of the image quality is improved. Fig. 2 shows the reference Bayer CFA pattern. To interpolate the missing G value at $R7$ pixel, we have to calculate the K_R's value around, i.e. K_R3, K_R6, K_R8, and K_R11. Since we do not have the R's value around $R7$, only estimated value is obtained. For example, we use the average of $R1$ and $R7$ to estimate $R3$, the average of $R5$ and $R7$ to estimate $R6$ as shown in equation (3) and (4).

$$K'_R3 = G3 - R'3 = G3 - (R1 + R7)/2 \quad (3)$$

$$K'_R6 = G6 - R'6 = G6 - (R5 + R7)/2 \quad (4)$$

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(a) G channel image (b) K_R image (c) K_B image

Figure 1 Example of G channel image, K_R image and K_B image

R	G	R1	G	R
G	B2	G3	B4	G
R5	G6	R7	G8	R9
G	B10	G11	B12	G
R	G	R13	G	R

Figure 2 Reference Bayer CFA pattern

2.1. G Channel Interpolation

To find the missing G value, we have to calculate the K_R's or K_B's value around it first. Refer to Fig. 1, the missing G value at $R7$ pixel is calculated as equation (5).

$$G'7 = R7 + (K'_R3 + K'_R6 + K'_R8 + K'_R11)/4 \quad (5)$$

where K'_R's is defined in equations (3) and (4).

The interpolation of G value at a B pixel, which is performed in the K_B domain, is similar.

2.2. R, B Channels Interpolation

Although the design of the proposed method is focused on improving the quality of the G images, we have also developed the corresponding interpolation method for R, B channels based on the same image model and the quality of the interpolated R, B images are satisfied.

Referring to Fig. 2, the proposed R, B interpolation is equivalent to a bilinear interpolation performing in the K_R or K_B domains.

$$R'3 = G3 - (K'_R2 + K'_R4)/2 \quad (6)$$

$$B'7 = G'7 - (K'_B2 + K'_B4 + K'_B10 + K'_B12)/4 \quad (7)$$

3. EXPERIMENT RESULTS

In this paper, four benchmark images in the Kodak photo sampler are chosen, as shown in Fig. 3. These benchmark images are sampled with Bayer CFA pattern to produce mosaic images, and then used as the input for interpolation. Table 1 shows the PSNR of the interpolation results. The G channel of the proposed method outperforms 6.34dB over bilinear method, and the R, B channels have 7.69dB improvement in average. The performance of the proposed method is obviously better than the conventional methods. In order to compare the visual quality, we magnify the interpolation results to show the details of the images. As shown in Fig. 4, the first column is the original images. Results of bilinear interpolation and the edge-sensing method are placed at the second and the third column, respectively. The last column is the results of the proposed method. We see that the results of the proposed method are obviously better than the conventional methods, and are not distinguished form the original images. For example, the word "Bahamas" of the proposed method is even sharper. The word "SMITH" on the helmet, and the word "SIX-SHOOTER" on the airplane are more obvious are more obvious than the results of the edge-sensing method. Meanwhile there are some hue changes in the feather of the parrot for both bilinear and edge-sensing methods, but not for the proposed scheme.

4. DISCUSSION

Refer to section 2, the proposed method requires only add and shift operations to implement. Since multiplier and divider are not required, hardware implementation is add and shift operations to implement. Since multiplier and divider are not required, hardware implementation is simple and the cost is reduced. Table 2 shows the complexity comparison of those interpolation methods. The proposed method almost triples the complexity of bilinear interpolation, but this low complexity increment is in fact worth to improve the image quality. Obviously, the proposed method is a better choice than the edge-sensing method from both complexity and image quality viewpoints.

5. CONCLUSION

A new CFA interpolation method is proposed in this paper. Real-world image simulation shows that the proposed method produces superior PSNR and better image quality performance. The G channel of the proposed method outperforms 6.34dB over bilinear method, and the R, B channels have 7.69dB improvement in average. Furthermore, the complexity of the proposed method is acceptable, only add and shift operations are required.

6. REFERENCES

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Table 1 PSNR of the interpolation results

Image	Bilinear Method			Edge-sensing Method			Proposed Method		
	R	G	B	R	G	B	R	G	B
Cap	28.37	35.10	30.87	30.87	35.51	31.38	35.79	41.20	35.04
Motor	20.74	27.23	20.66	22.68	27.51	24.23	30.11	34.76	29.72
Airplane	25.75	32.48	25.42	29.54	32.95	28.82	33.82	38.41	32.69
Parrot	29.57	36.11	29.20	30.92	36.33	32.92	35.89	41.90	36.63

Table 2 Complexity comparison of bilinear, edge-sensing, and the proposed method

Operation	Bilinear Method		Edge-sensing Method		Proposed Method	
	G	R/B	G	R/B	G	R/B
Add	3	4	7	4	8	12
Shift	1	2	3	2	3	2
Multiplication				2		
Division				6		
Comparison			1			
Absolute value			2			

Figure 3 Four benchmark images in Kodak photo sampler

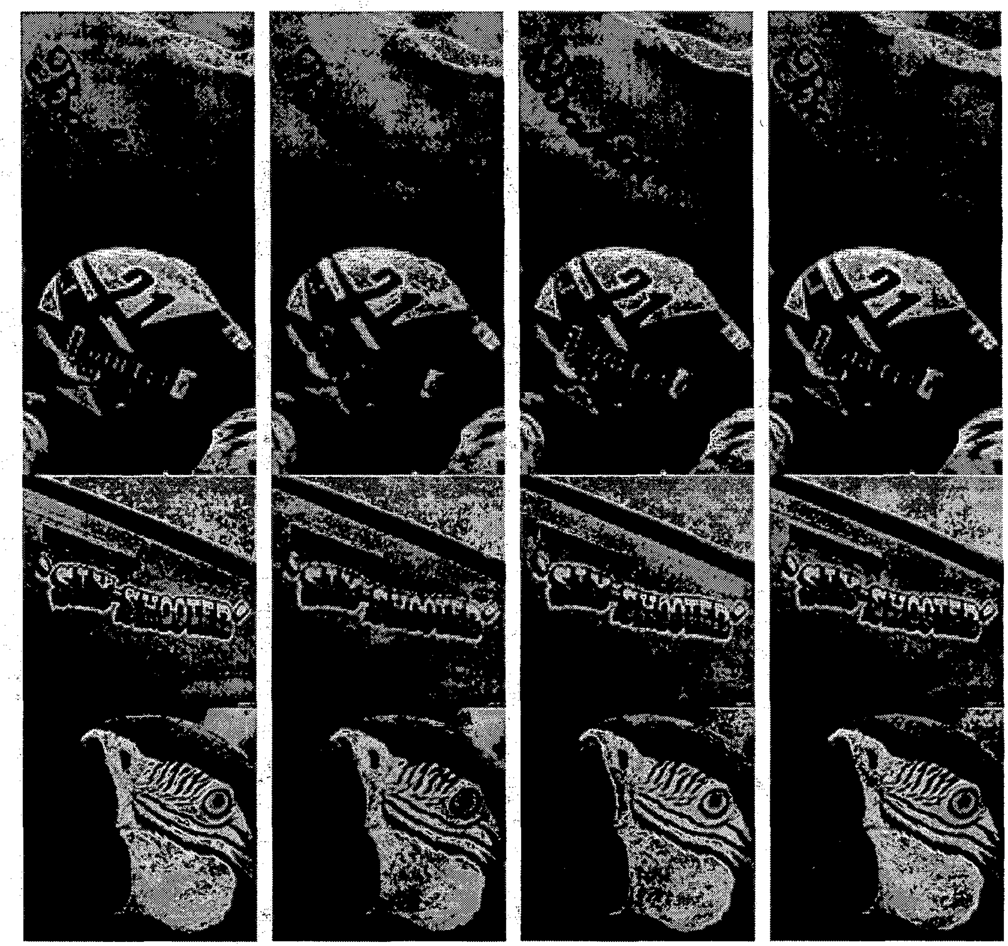

Figure 4 Detailed images of the interpolation results. The first column is the original image. The second and the third column are the result of bilinear and edge-sensing method, respectively. The last column is the result of the proposed method.