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Different Color Union for Single Sensor Interpolation

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Abstract

This paper introduces a single sensor interpolation method for a different color assigned single sensor color camera. The presented method especially describes the performance among three different color combinations, such as RRGB, RGGB, and RGGB. The Bayer pattern has been widely used, and nowadays the research on X-Trans pattern is well studied. The proposed method substitutes the dominant color to the other color of two, and evaluates the performance. In any case, the three color potion is one of three, 2:1:1, 1:2:1, or 1:1:2. Simulation results display the MSE and PSNR results and the obtained images.

Keywords: *color filter array interpolation, single sensor interpolation, color pattern*

1. Introduction

The mosaic pattern is a color filter array (CFA) for associating red, green, and blue color filters on a square grid of single sensors [1]. Interpolation is a basic tool to resize a given image [2-8]. The Bayer color pattern has been widely used in general single sensor digital cameras, and also used in scanner sand camcorders to reproduce a color image. The color assignment of each pattern is 1:2:1 (*red*:*green*:*blue*), therefore these patterns can be either following three: RGGB, RGBG, or GRGB as shown in Figure 1.

(a) (b) (c)

Figure 1. (a) The original Bayer pattern and (b,c) its two alternatives

Recently, alternatives to the Bayer pattern CFA have been presented. In particular, the Fujifilm X-Trans CMOS sensor was presented to yield better resistance to color artifact than the original Bayer CFA, and therefore X-Trans CFA can be fabricated without an anti-aliasing filter [9]. In the same manner, there are number of new designs that argue to provide

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higher performance with the same complexity and with less false color. Figure 2(a) shows the original X-Trans CFA pattern, and Figure 2(b) and 2(c) are its alternatives.

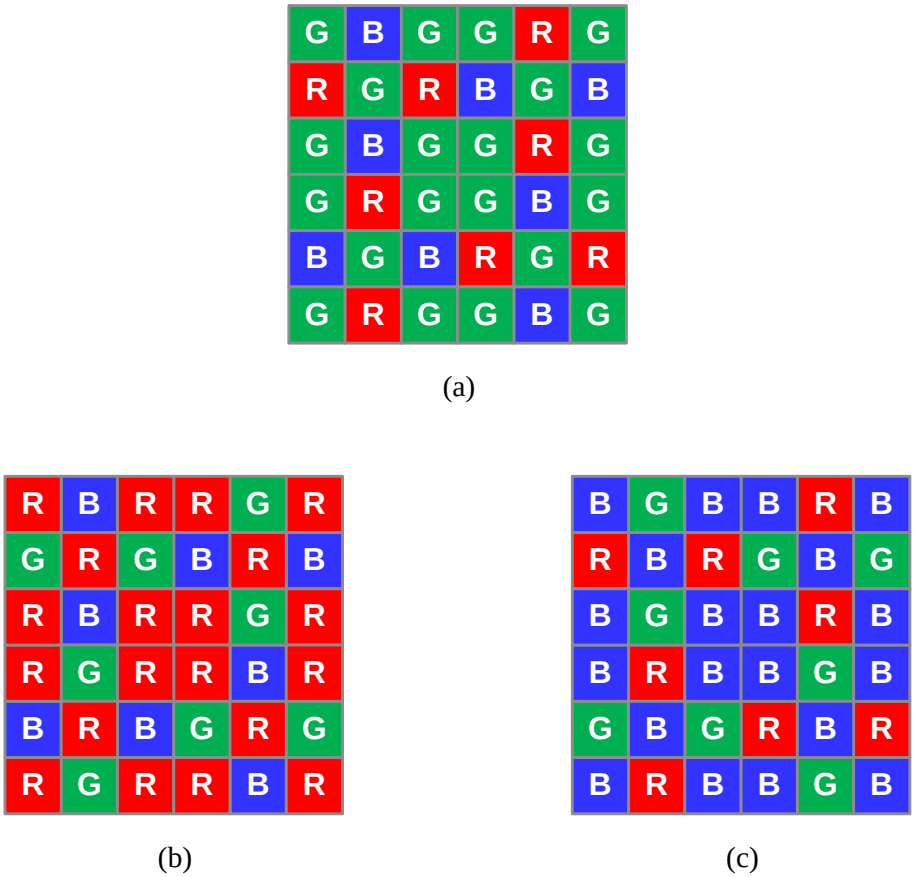


Figure 2. X-Trans CFA patterns: (a) RGGB, (b) RRGB, (c) RGBB

Although the Bayer CFA has been dominant in consumer digital cameras, with the proposal of Fujifilm X-Trans CMOS sensor, different alternatives are nowadays proposed.

In this paper, we present different color combined X-Trans CFA patterns and its performance. The proposed method is provided in Section 2. In Section 3, simulation results are described. Finally, we conclude this paper in Section 4.

2. Proposed Method

As can be seen in Figure 2, X-Trans CFA consists of three colors: red, green and blue. Thus, Figures 2(a), 2(b), and 2(c) can be decomposed as Figure 3.

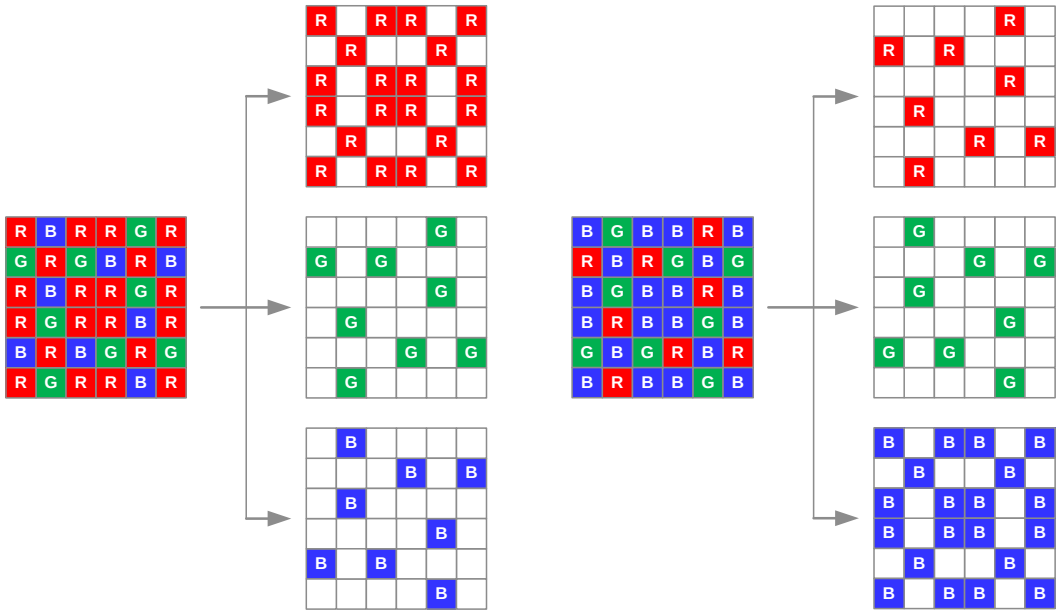


Figure 3. Decomposed colors of X-Trans CFA alternatives: (a) RRGB, (b) RGBB

To design filters we adopt error minimization approach. The principal limitation of color demosaicking methods is that they are not intended to design to minimize error or information loss. To this end, many researchers have been studying error minimization methods such as least squares method [10]. Although least squares method is a popular solution, it has limitation that it does not consider the visual aspects [11]. However, this is out of scope of this research. In this paper, we present filter that were designed based on least squares methods. All designed filters are pre-obtained before the color interpolation because it is assumed that we know the original image. The goal of this work is to minimize the error between the original image and the obtained filter-based reconstructed image.

Let us assume that **a** is *n*-by-1 constant vector to be estimated, and **b** is *n*-by-1 output vector. Then **a** and **b** are constant vector and measurements, respectively. The goal of this work is to estimate **a**. Another assumption that we admit is that we assume **b** is faultless. Then, **b** can be described as Eq. (1).

$$\mathbf{b} = \mathbf{H}\mathbf{a} \tag{1}$$

Then, estimation can be obtained using inverse transformation,

$$\hat{\mathbf{a}} = \mathbf{H}^{-1}\mathbf{b} \tag{2}$$

Here, obtaining **H** is the work of filter design, and obtaining **a** is the goal of demosaicking. In general, the given data is not always perfect. Thus, we can further consider noise added data case. When the measurements are equally uncertain, we can make this model,

$$c_i = a + n_i \tag{3}$$

Then, Eq. (3) can be expressed as

$$\mathbf{c} = \mathbf{H}\mathbf{a} + \mathbf{n} \tag{4}$$

Then, the optimal estimation can be performed as

$$\hat{\mathbf{a}} = \left(\mathbf{H}^{\mathbf{T}}\mathbf{H}\right)^{-1}\mathbf{H}^{\mathbf{T}}\mathbf{c} \tag{5}$$

Figure 4 shows an example of least squares method [12].

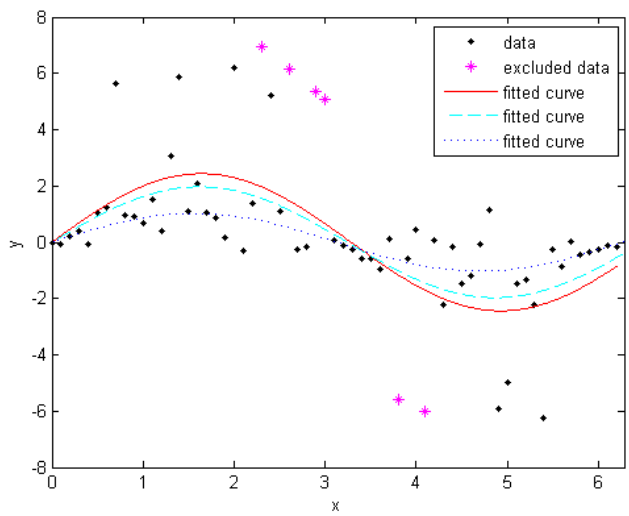
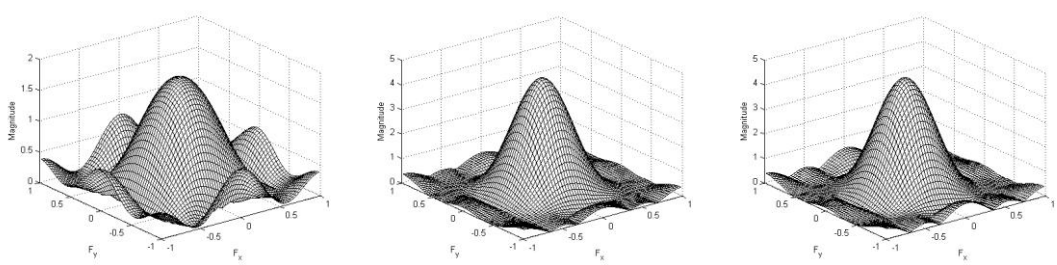


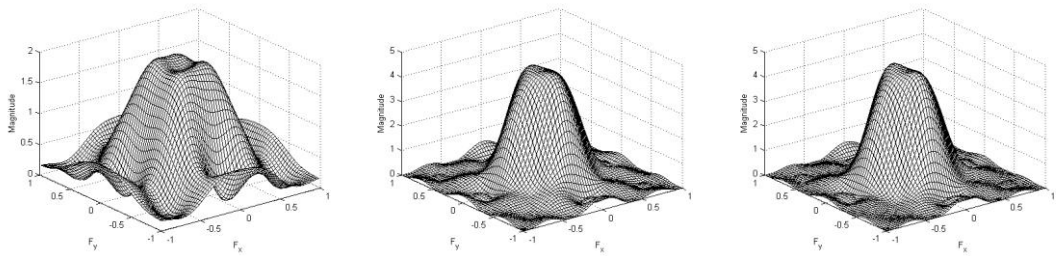
Figure 4. Example of least squares methods

The designed filters' frequency responses are shown in Figure 5. Figure 5(a) is the frequency response of red channel of Figure 3(a). In the same manner, Figures 5(b) and 5(c) are frequency responses of green and blue channels of Figure 3(a). All filters were designed with 5x5 size.



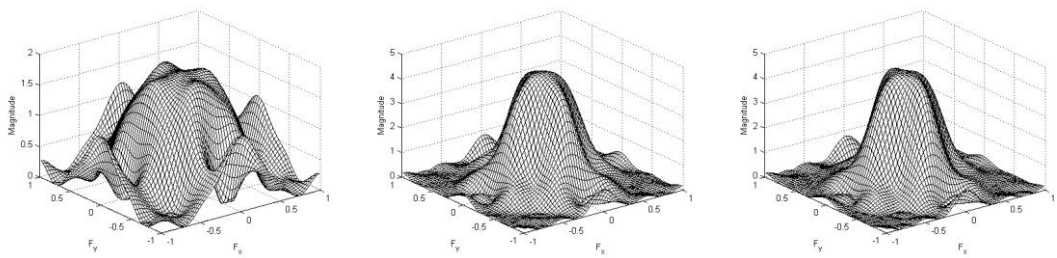
(a) (b) (c)

Figure 5. Designed 5x5 filters on Figure 3(a): (a) red channel, (b) green channel, (c) blue channel



(a) (b) (c)

Figure 6. Designed 7x7 filters on Figure 3(a): (a) red channel, (b) green channel, (c) blue channel



(a) (b) (c)

Figure 7. Designed 9x9 filters on Figure 3(a): (a) red channel, (b) green channel, (c) blue channel

3. Simulation Results

The proposed scenario was tested on the LC dataset of color test-images and has been compared with other color combinations. The employ two metrics, MSE and PSNR dissimilarity function, in decibels (dB).

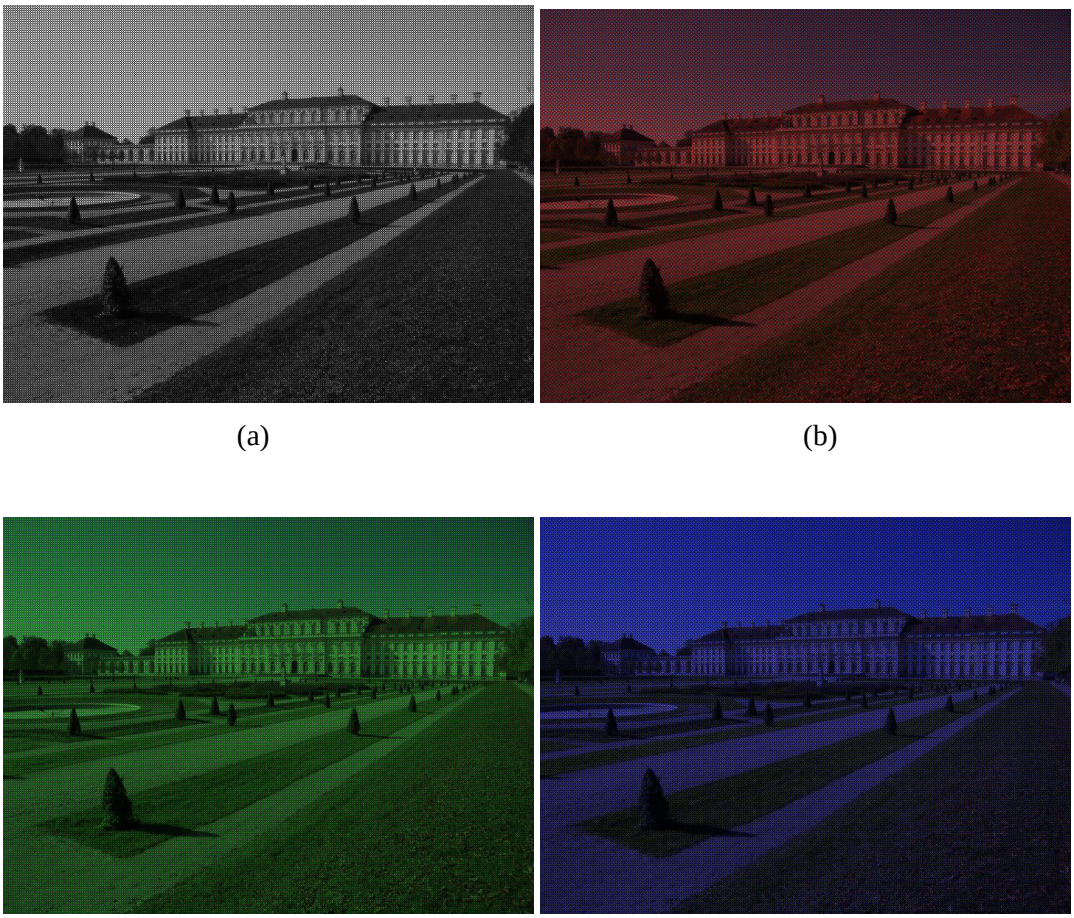
$$MSE\left(img_{org}, img_{rec}\right) = \sum_{p=1}^{width} \sum_{q=1}^{height} \frac{\left(img_{org}\left(p,q\right) - img_{rec}\left(p,q\right)\right)^2}{width \times height} \tag{6}$$

$$PSNR\left(img_{org}, img_{rec}\right) = 10\log_{10} \frac{255^2}{MSE\left(img_{org}, img_{rec}\right)} \tag{7}$$

where img_{org} and img_{rec} are the original and the restored images, respectively. The numerical results are summarized in Table 1 for 150 LC images.

Columns 2-5 are MSE results in red, green, blue and their average results, respectively. The last four columns are PSNR results in red, green, blue and their average results, respectively. From the results, it was found that RGGB yields the best performance.

Figure 8 shows X-Trans CFA images. Figure 8(a) is the black and white image of RRGB X-Trans CFA. Figures 8(b,c,d) are RRGB, RGGB, and RGBB X-Trans CFA of color images. The test images were obtained from LC dataset.

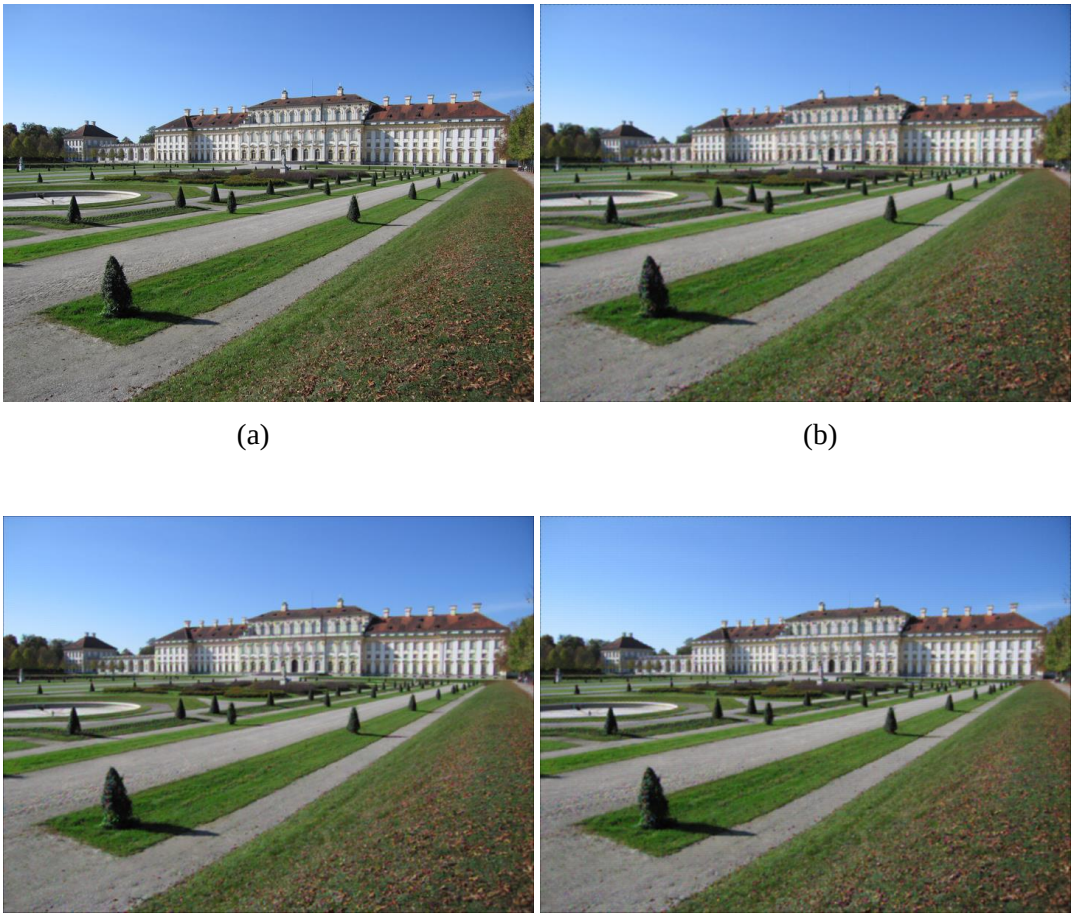


(a) (b)

(c) (d)

Figure 8. X-Trans CFA images of 31st LC image: (a) black and white image, (b) RRGB, (c) RGGB, and (d) RGBB

Figure 9 shows the reconstructed images of CFA patterns shown in Figure 8.



(a) (b)

(c) (d)

Figure 9. (a) Original of 31st LC image, (b) Reconstructed image from RRGB, (c) Reconstructed image from RGGB, and (d) Reconstructed image from RGBB

Table 1. Performance comparison

	MSE				PSNR (dB)			
Channel	Red	Green	Blue	Average	Red	Green	Blue	Average
RRGB	145.51	205.81	180.02	177.11	26.58	25.06	25.69	25.73
RGGB	185.60	162.17	180.02	175.93	25.52	26.10	25.69	25.76
RGBB	185.60	206.61	140.47	177.56	25.52	25.04	26.78	25.72

4. Conclusions

Color demosaicking is important interpolation tool for single sensor color camera. In this paper, we introduced a single sensor interpolation approach for three different CFA patterns, RRGB, RGGB, and RGBB. Although Bayer pattern CFA is widely used in the field, we used Fujifilm X-Trans CMOS sensor in this study. Filters were designed by least square methods which minimize interpolation errors. The performance of three patterns has been compared in PSNR and it was clearly seen that RGGB pattern was the best.

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