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Color Reconstruction for CFA Images

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Abstract

The color image enhancement is an important topic for last few decades and still many researchers are working and presenting their research findings in literature. There are two issues in digital camera, firstly color filtering and secondly low spatial resolution. To solve both issues, this paper presents a new super resolution approach. Although Bayer pattern CFA is widely used in camera industry, there are few alternatives such as X-Trans CFA pattern. As color restoration method for X-Trans CFA pattern is not many, this paper introduce filter based demosaicking method. We firstly design filters then apply it to X-Trans CFA pattern. Then, full color images are obtained. Experimental results indicate that the presented method provides satisfactory results.

Keywords*: X-Trans, color filter array, super resolution, image processing*

1. Introduction

The digital color images are generally indicated by three color levels (red, green, and blue) at each pixel, and the camera estimates three spectral measurements per each pixel [1-2]. This camera differentiates the light and displays it onto three single electronic sensors such as CCD or CMOS [3-6]. However, this array requests its appropriate driving electronics, and the corresponding three color images have to be registered accurately [7-8]. This process is time consuming work and causes additional costs. Therefore, most digital cameras adopt a single matrix assessing a single color per pixel [9]. The digital cameras have been attracting great favor with consumers and replaced their film-based cameras in various applications over the past few decades [10-14]. As a pixel contains only single color information, the other two color information should be restored from the adjacent pixels, and this process is called demosaicking [15].

There are various configurations of sensor array, and Bayer color filter array (CFA) is one of the most well-known CFA patterns [16]. In this pattern, a sing pair has four pixels. Two pixels are obtained from green information and the other two are obtained from red and blue information. It is noted that the green information is arrayed in quincunx pattern.

There are several demosaicking methods that were presented to reduce the color artifacts with less computational time. Some of them are based on nearest neighbor, bilinear, or bicubic interpolation methods, which are assumed as simple methods. These methods are single channel based approaches. Although these methods are simple, their results images may contain color artifacts.

In this paper, we investigate X-Trans CFA pattern and its demosaicking algorithm. This paper is organized as follows. In Section 2, the proposed method is presented where X-Trans CFA and its corresponding demosaicking method are explained. In Section 3, we explain the visual and objective performance comparison. Finally, Section 4 shows the concluding remarks.

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2. Proposed Method

The X-Trans CFA pattern has higher degree of randomness with an array of six-by-six pixel units which has 8 red pixels, 20 green pixels, and 8 blue pixels. This CFA pattern was presented by Fujifilm Company to try to lessen moiré and false color artifacts, and reconstruct high resolution images. Generally speaking, the Bayer pattern CFA uses anti-aliasing filters to reduce moiré effect. However, the X-Trans CFA sensor adopts inconsistent pattern, which make it more possible to reduce severe moiré and false color artifacts effect.

Figure 1. X-Trans CFA Pattern

Although the X-Trans CFA pattern is inconsistent (as can be seen in Figure 1), all horizontal or vertical lines have at least one R, G, and B pixel. This is big difference between the Bayer CFA pattern and the X-Trans CFA pattern, where horizontal or vertical lines do not have all three color components (Bayer CFA pattern). Another reason X-Trans CFA pattern is superior to Bayer CFA pattern is that, the X-Trans CFA pattern obtains more light than Bayer CFA pattern.

Figure 2 shows the process of color restoration for X-Trans CFA pattern. Figure 2 shows color restoration procedure for X-Trans CFA pattern. Figure 2(a) shown in the first column displays the X-Trans CFA pattern. Figure 2(b) shown in the second column displays three different color channels, red, green, and blue, where each six-by-six pair has 2:5:2 color components. This figure explains why green channel has more green information than that of Bayer pattern CFA case (1:2:1). Figure 2(c) shown in the third column displays the reconstructed image. Finally, Figure 2(d) shown in the last column displays the full color reconstructed image.

Figure 3 shows actual X-Trans pattern in 128th image, where 103 to 114 of x-axis, and 103 to 114 of y-axis are displayed. Figures 3(a) to 3(d) show red, green, blue, and CFA images.

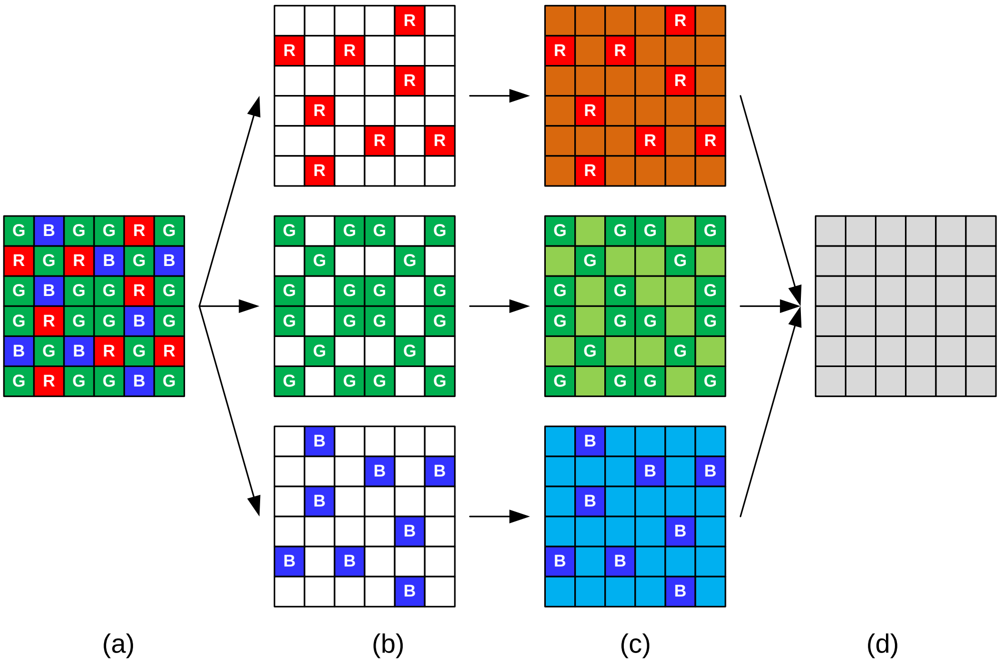


Figure 2. Color Restoration Process for X-Trans CFA Pattern

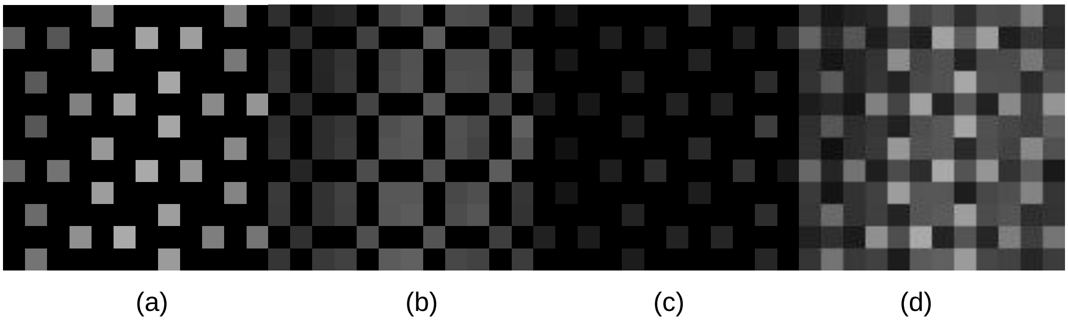


Figure 3. Actual X-Trans CFA Pattern for 128th Image, *X*-Axis 103 t 114 Location, *Y*-Axis 103 to 114 Location: (a) Red Channel, (b) Green Channel, (c) Blue Channel, (d) CFA Image

The proposed filter is designed by least squares method. The characteristics of linear time-invariant (LTI) systems are mainly defined by their impulse response. The output of the LTI system to any input $x(i,j)$ can be determined via a convolution with the impulse response $h(i,j)$:

$$y(i,j)=x(i,j)*h(i,j) \tag{1}$$

Above equation is spatial domain representation, which can be represented in frequency domain as shown in Eq. (2),

$$Y(u,v)=X(u,v)H(u,v) \tag{2}$$

Both equations indicate that the convolution of spatial domain is identical process of multiplication of frequency domain. This process can be used in several applications such as low-pass filter, band-pass filter, high-pass filter, and unsharp masking. To design these filters, we use standard least squares method. Our desired filter must be with minimized filter length, minimized error between original and the restored images, and minimized computational complexity.

The purpose of designing our filter is to obtain a filter *h* that minimizes the errors, in other words, the output obtained by *h* is the most approximately similar to the original one.

$$Kh = H \quad (3)$$

where K is the Fourier matrix and H is the frequency response. To solve this equation in a least squares sense, we calculate error cost as follows,

$$error = |Kh - H| \times |Kh - H| . \quad (4)$$

To solve this equation, one must minimize *error* cost with differentiate with respect to filter h,

$$\frac{d}{dh} error = 2K^T |Kh - H| \quad (5)$$

This equation can be rearranged as

$$2K^T |Kh - H| = 2K^T Kh - 2KH \quad (6)$$

Then, the filter h is obtained as,

$$h = \left(K^T K \right)^{-1} K^T H \quad (7)$$

Filter h is the result of the standard least squares form.

3. Simulation Results

In this section, we used 20 natural images of LC dataset, which has the size of 720×540 or 540×720. Out of 150 LC images, we selected #111-130 images. The color PSNR is defined as follows:

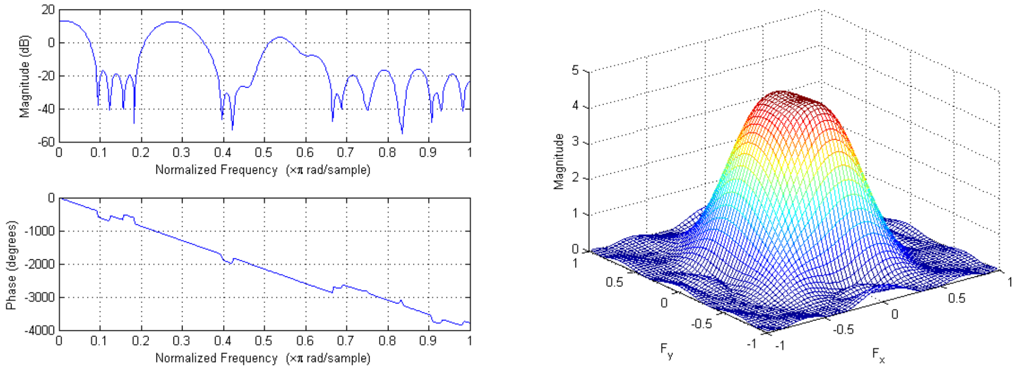
$$CPSNR = 10 \log_{10} \left(\frac{255^2 \times 3}{\sigma^2} \right) \quad (8)$$

where σ is

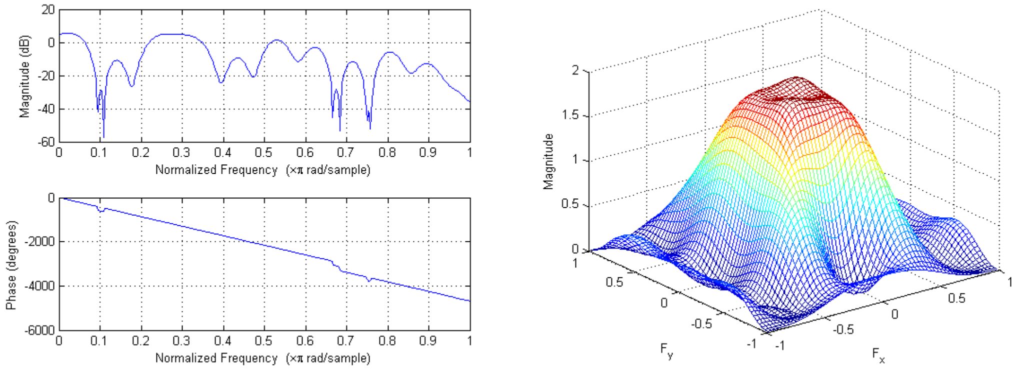
$$\sigma^2 = \frac{1}{NM} \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} \left\{ \left| R(i,j) - R(i,j) \right|^2 + \left| G(i,j) - G(i,j) \right|^2 + \left| B(i,j) - B(i,j) \right|^2 \right\} \quad (9)$$

and MN is the size of an image. A pixel of a color image can be assumed as a three dimensional vector.

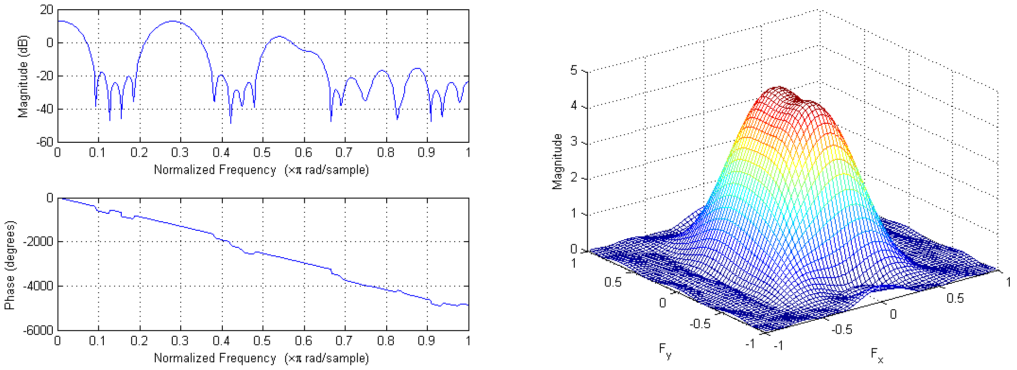
Figures 4-6 show 1D magnitude & phase and 2D frequency response X-Trans CFA pattern of #128-130 LC images. Each figures in (a), (b) and (c) are red, green, and blue channel results.



(a)

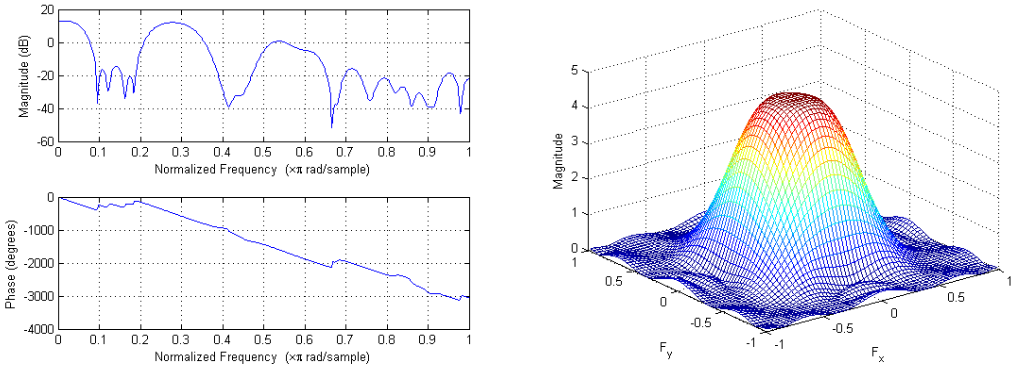


(b)

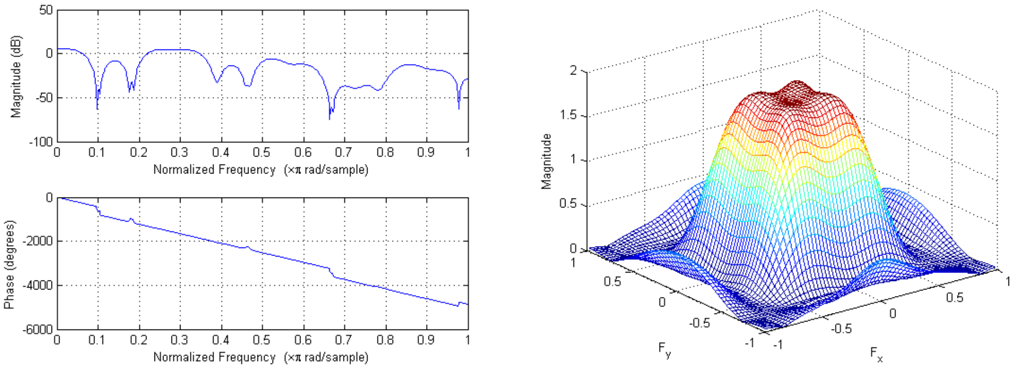


(c)

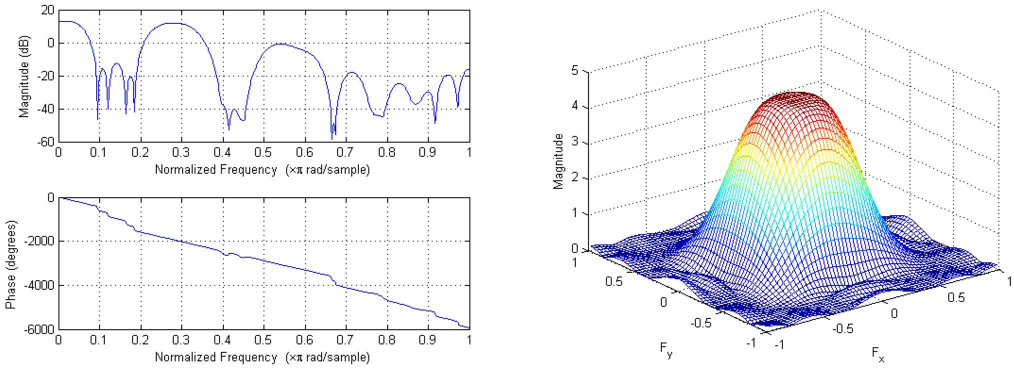
Figure 4. X-Trans CFA Pattern of 128th LC Image, 1D Magnitude & Phase and 2D Frequency Response: (a) Red Channel Filter, (b) Green Channel Filter, and (c) Blue Channel Filter



(a)

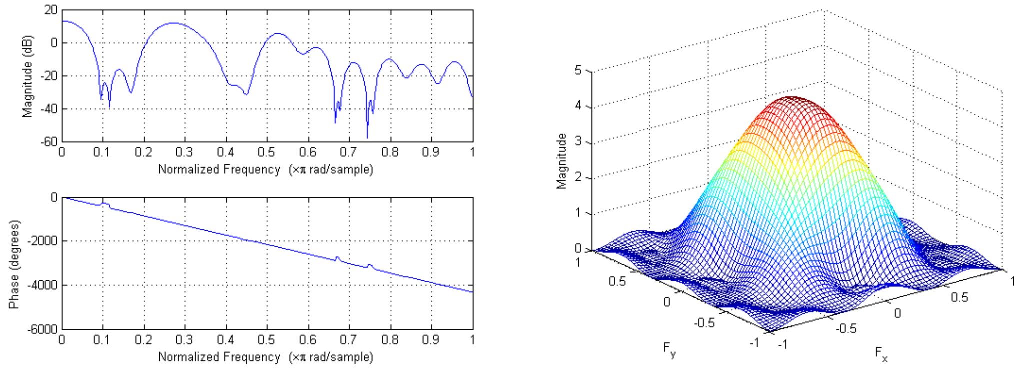


(b)

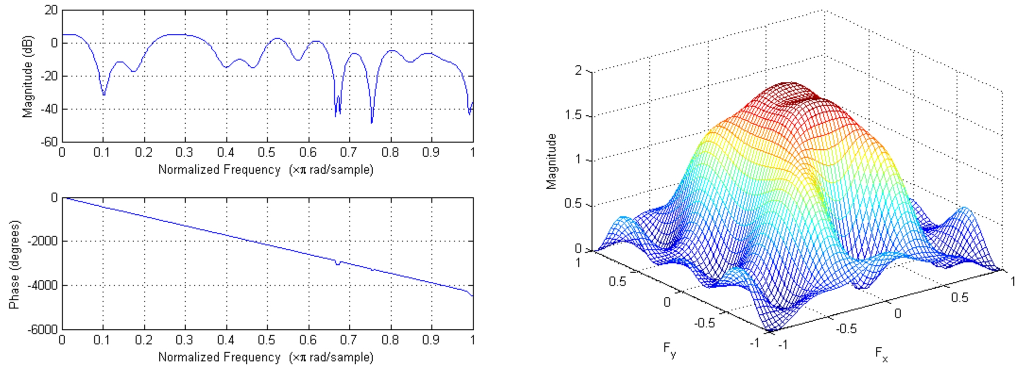


(c)

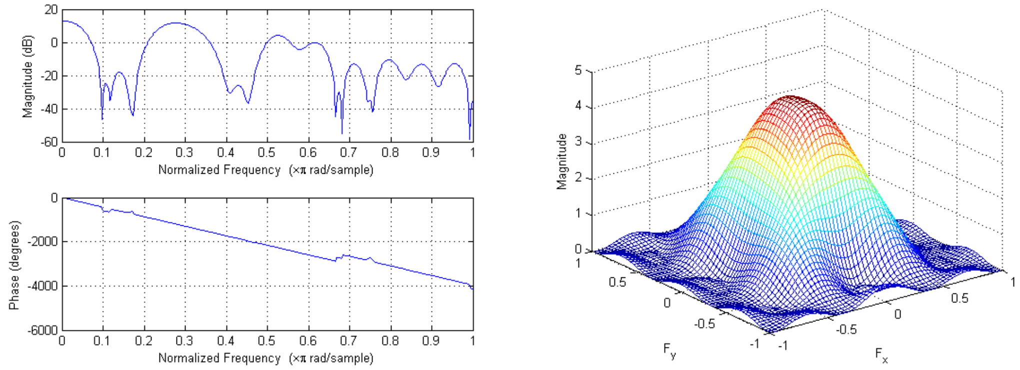
Figure 5. X-Trans CFA Pattern of 129th LC Image, 1D Magnitude & Phase and 2D Frequency Response: (a) Red Channel Filter, (b) Green Channel Filter, and (c) Blue Channel Filter



(a)



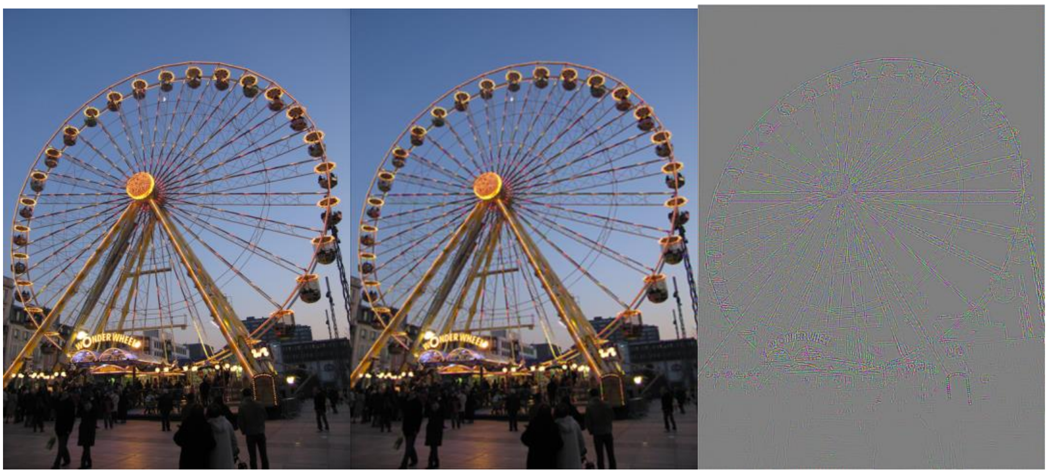
(b)



(c)

Figure 6. X-Trans CFA Pattern of 130th LC Image, 1D Magnitude & Phase and 2D Frequency Response: (a) Red Channel Filter, (b) Green Channel Filter, and (c) Blue Channel Filter

Figures 7 and 8 show color restored images on #115 and #129 images. Figures 7(a) and 8(a) show the original image and Figs. 7(b) and 8(b) show color restored image. Figures 7(c) and 8(c) show the difference image between the original and the color restored image.



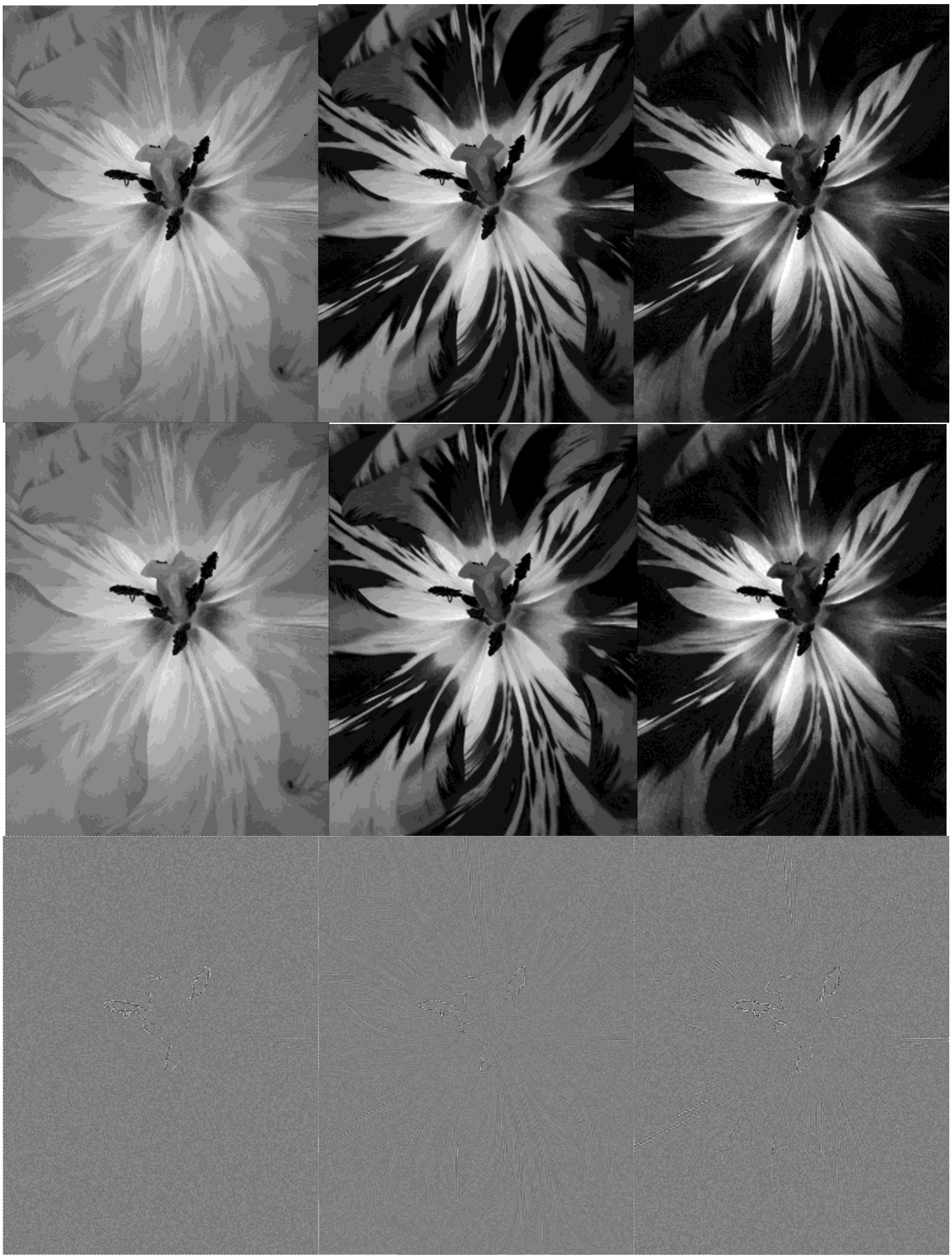
(a) (b) (c)

Figure 7. Visual Performance Comparison: (a) 115th Original Image, (b) Restored Image, and (c) Difference Between the Original and the Restored Image

(a) (b) (c)

Figure 8. Visual Performance Comparison: (a) 129th Original Image, (b) Restored Image, and (c) Difference Between the Original and the Restored Image

Figure 9 shows subjective performance comparison images. Three top images are original red channel, green channel, and blue channel images, and three images in the middle are restored images, and three bottom images are difference images between the original and the restored images.



(a) (b) (c)

Figure 9. Visual Performance Comparison, Original Image (Up), Restored Image (Middle), Difference Between Original and Restored Images (Down): (a) Red Channel, (b) Green Channel, and (c) Blue Channel

Tables 1 and 2 show objective performance results. Tables 1 and 2 show the MSE and PSNR results in terms of red channel, green channel, blue channel, and color results.

Table 1. MSE Results For Restored X-Trans CFA Pattern Images

	MSE_{Red}	MSE_{Green}	MSE_{Blue}	CMSE
111	196.826	133.039	182.198	170.688
112	121.992	86.697	109.580	106.090
113	249.109	158.041	195.099	200.749
114	96.912	62.564	65.756	75.078
115	172.028	145.537	233.618	183.728
116	83.745	59.681	95.536	79.654
117	163.471	123.475	132.467	139.804
118	241.452	160.777	217.251	206.493
119	43.233	28.935	32.988	35.052
120	106.032	65.910	94.336	88.760
121	243.488	152.449	235.636	210.524
122	114.793	76.622	124.812	105.409
123	74.115	26.064	52.238	50.806
124	29.551	31.272	52.960	37.927
125	137.100	85.156	146.884	123.047
126	12.412	9.991	13.470	11.958
127	220.919	168.171	228.879	205.990
128	69.962	55.836	36.458	54.085
129	10.013	13.541	25.925	16.493
130	23.968	19.653	42.066	28.562
avg.	120.556	83.171	115.908	106.545

Table 2. PSNR Results for Restored X-Trans CFA Pattern Images

	$PSNR_{Red}$	$PSNR_{Green}$	$PSNR_{Blue}$	CPSNR
111	25.190	26.891	25.525	25.809
112	27.267	28.751	27.734	27.874
113	24.167	26.143	25.228	25.104
114	28.267	30.168	29.951	29.376
115	25.775	26.501	24.446	25.489
116	28.901	30.372	28.329	29.119
117	25.996	27.215	26.910	26.676
118	24.303	26.069	24.761	24.982
119	31.773	33.517	32.947	32.684
120	27.876	29.941	28.384	28.649
121	24.266	26.300	24.408	24.898
122	27.532	29.287	27.168	27.902
123	29.432	33.970	30.951	31.072
124	33.425	33.179	30.891	32.341
125	26.760	28.829	26.461	27.230
126	37.192	38.135	36.837	37.354
127	24.688	25.873	24.535	24.992
128	29.682	30.662	32.513	30.800
129	38.125	36.814	33.994	35.958
130	34.335	35.196	31.892	33.573
avg.	28.748	30.191	28.693	29.094

4. Conclusions

In this paper, we investigated X-Trans CFA pattern and its corresponding demosaicking algorithm. To solve two main issues in digital camera, color filtering approach and filter design approach were studied. To this end, a new filter based upsampling method was presented. By applying filters designed for X-Trans CFA pattern, we could achieve satisfactory objective and subjective performance.

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