

# Noise Model Analysis on Image Sensor Arrays

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## **Abstract**

*This paper presents a new noise model and its application to Bayer color filter array (CFA). We investigate the effect of various noise models. In addition, we study three possible Bayer patterns. For example, current Bayer CFA utilizes RGGB pattern. However, one may consider other color combinations such as RRGB or RGBB patterns. To prove RGGB pattern's superiority, we investigate each pattern in various noise model and noise level. We also studied the method how to generate noisy image from noisy free image. Traditional noise models do not take into account white balance, gamma and tone correction issues. Simulation results indicate that the new noise model is more reasonable than the conventional models.*

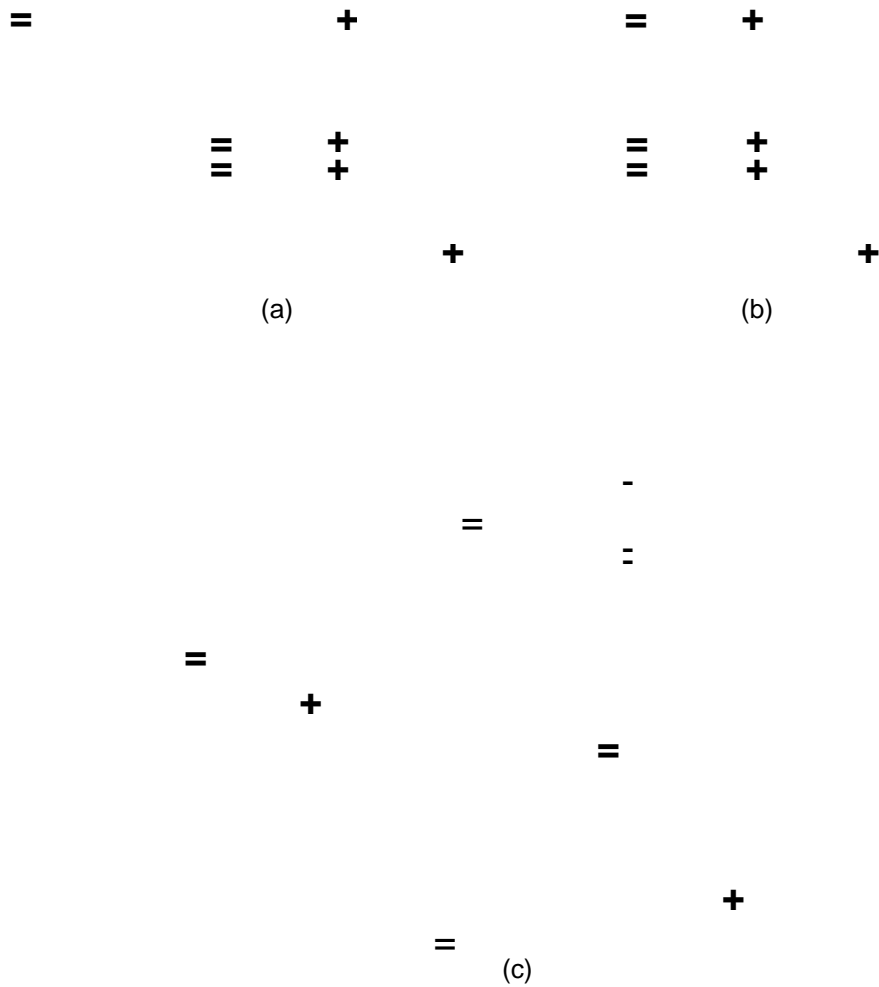
**Keywords:** *Noise model, color image, color interpolation, color combination*

## **1. Introduction**

The light was studied by Newton who explained that white light includes every possible spectral colors [1-2]. Therefore, if all colored lights are added, it becomes white color. In contrast, when specific spectral color is excluded from the white light, complementary color is revealed [3-6]. In general, to generate certain color image, it is required to have three colors: red, green, and blue. These three colors are noted as primary colors. There are two color rules to generate colors. One is additive color and the other one is subtractive color. The former one is used for blending lights. In contrast, subtractive color is used by subtracting parts of the spectrum of light. The subtractive color is used for painting, dying, and inks.

For additive color system, the mixing of two or more primary colors in equal ratio will generate new colors [7]. For example, red and green generate yellow, red and blue generate magenta, and green and blue generate cyan [8]. In contrast, blue is generated by mixing magenta and cyan, green is generated by mixing yellow and cyan, and red is generated by mixing yellow and magenta [9-11]. Figure 1(a) shows the consequent color outcome of blending of three primary colors. The color of an object is given by materials. This is ruled by subtractive color, and the remaining light is returned to human eyes (Figure. 1b). Figure 1(c) implies a method to obtain certain color. For example, to obtain yellow, magenta, and cyan, one may take away blue, green, and red from white light.

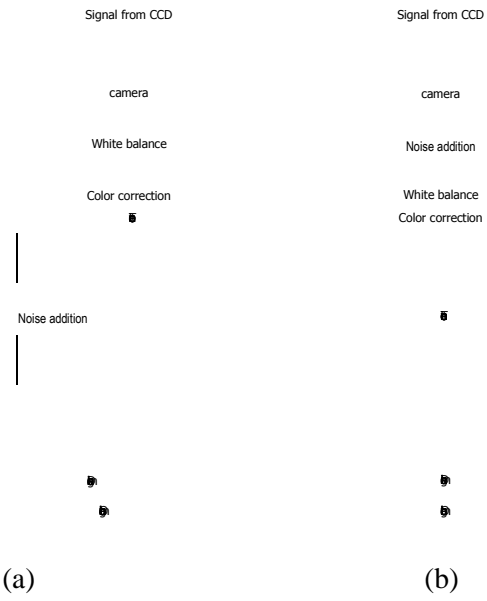
In this paper, we propose a new noise model and study its effects on Bayer CFA [12]. The remainder of this paper is as follows. Section 2 explains noise model. Section 3 explains possible color combinations for Bayer pattern. Section 4 describes simulation results and discussion. Finally, conclusion remarks are shown in Section 5.



**Figure 1. (a) Additive Color, (b) Subtractive Color, (c) Alternative Method to Generate Yellow, Magenta, and Cyan**

## 2. Proposed Noise Model

Generally speaking, image noise can be explained as a random variation of luminosity. The image noise can be generated by three sources: image CCD/CMOS sensor, scanner, and digital camera. In literature, various image noise models have been proposed. Their assumption are shown below:



**Figure 2. Comparison of Two Noise Model: (a) Conventional Noise Model, (b) Proposed Noise Model**

**Assume 1:** Consider noise is stationary, R G B color channels have the same standard deviation ( $\sigma_R: \sigma_G: \sigma_B=1:1:1$ ). [13]

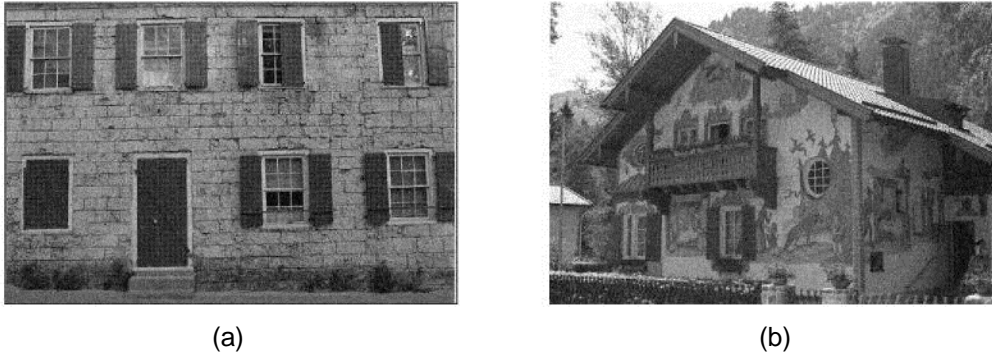
**Assume 2:** Sensor noise to be signal-dependent, being proportional to the signal magnitude plus a base level. Give noise arbitrary: ( $k_0, k_1$ ) = (0,0), (25,0), (25,0.1), (25,0.2). [14,15]

**Assume 3:** An assumption with signal-independent stationary noises of known variances  $\sigma_R: \sigma_G: \sigma_B=13:12:10$ . [16,17]

However, each model is based on tentative assumption or observation [18-25]. We assume the most reliable noise model should be the noise which is located before the white-balance, gamma-correction stages, and it should be signal-dependent and signal-independent white Gaussian noise. Moreover, the variance on three primary colors must be different ( $\sigma_R: \sigma_G: \sigma_B$ ) in each channels.

Our suggestion is to use other ( $\sigma_R: \sigma_G: \sigma_B=1.8:0.7:1.0$ ) variance combination. These ratio is obtained empirically. One of important conditions is that  $\sigma_G$  should be the smallest, while  $\sigma_B$  should be biggest. The reason behind this idea is that the human eye is most sensitive to green, and the least sensitive to blue. Figure 2 shows two noise models. The model in Figure. 2(a) is conventional noise model which is widely used for image denoising applications. In contrast, noise model in Figure. 2(b) is proposed model.

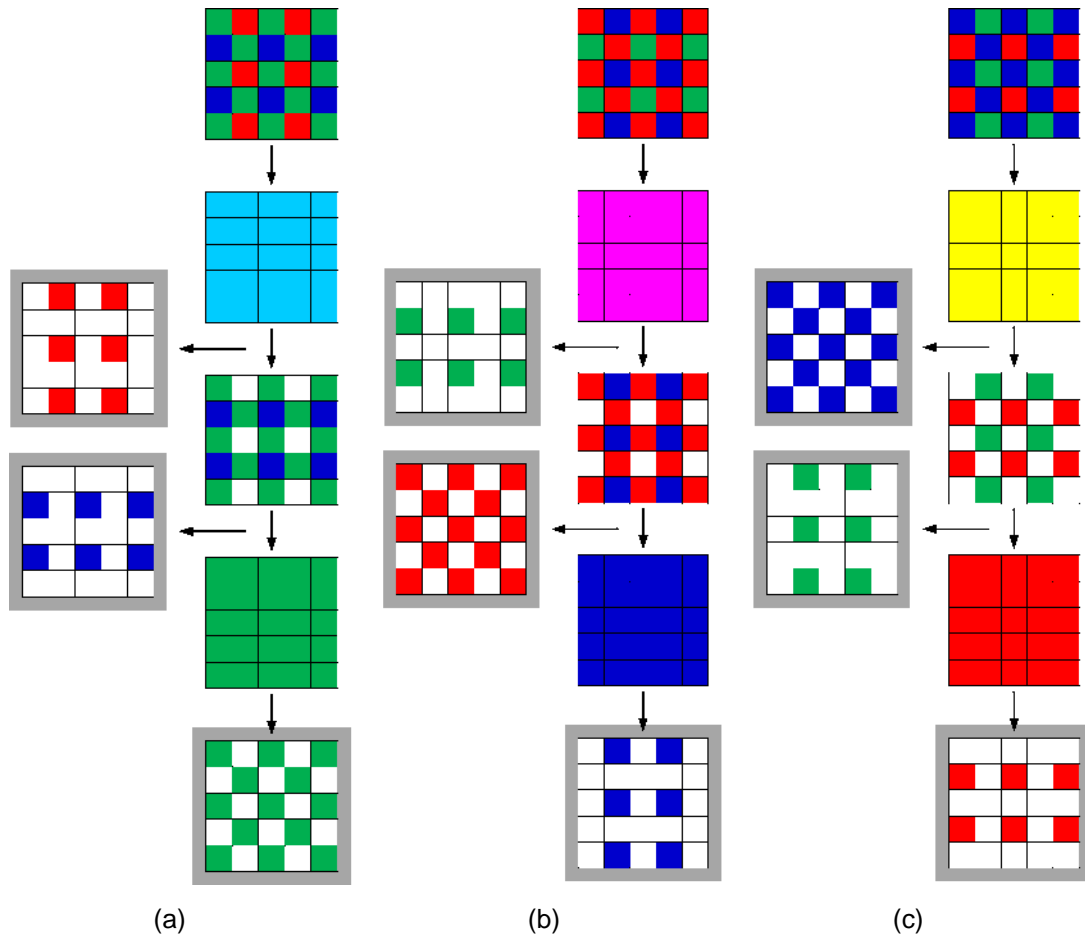
Some results of Figure. 2(a) and 2(b) are shown in Figure. 3. Noisy image shown in Figure. 3(a) is the 1st image of Kodak dataset. Figure 3(b) shows the noisy image of 24<sup>th</sup> Kodak dataset.



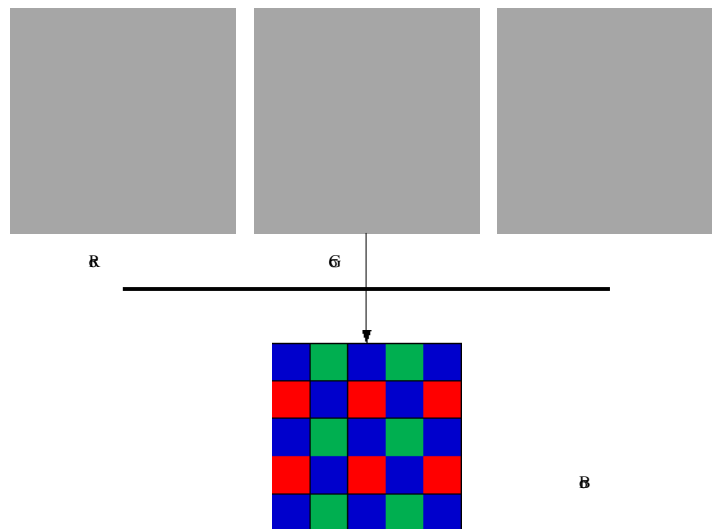
**Figure 3. Generated Noise Image with  $\sigma=20$ . (a) 1st Kodak Image, (b) 24th Kodak Image**

### 3. Possible Color Combination of Bayer Pattern

A Bayer color filter array (CFA) is widely adopted for digital camera. The Bayer filter alignment is a CFA for settling RGB color channels on a square grid of electronic sensors. The Bayer pattern alignment is utilized in most digital image sensors used in digital cameras. A pair of Bayer CFA pattern has four pixels and CFA pattern may be three candidates: RRGB, RGGB, and RGBB. For example, if RGGB is obtained, it has 2 green pixels, 1 red pixel and 1 blue pixel.



**Figure 4. Process of CFA Pattern Generation: (a) RGGB, (b) RRGB, and (c) RBBB**



**Figure 5. Process of Generating Noisy Image with Variance Level  $G_R$ ,  $G_G$ , and  $G_B$**

Figure 4(a) shows the process of obtaining RGGB patterned CFA. As we can see, by applying cyan filter, red channel is obtained. After that, by using green filter, blue channel

is obtained. The rest of signals are green channel. In the same manner, RRGB case (Figure. 4b) and RGBB case (Figure. 4c) are explained. Figure 5 shows the process of generating noisy image with variance level  $\sigma_R$ ,  $\sigma_G$ , and  $\sigma_B$ .

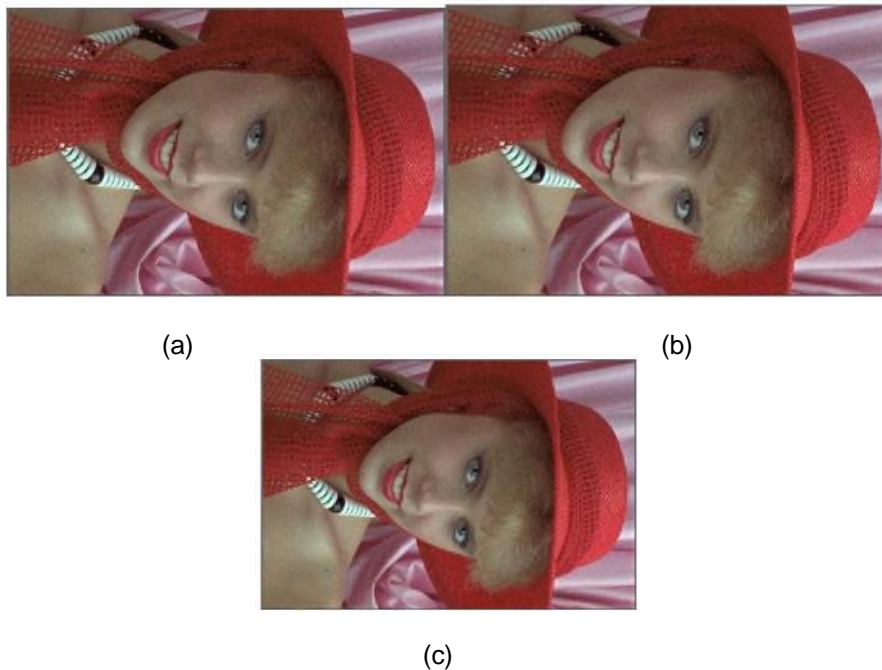
#### 4. Simulation Results



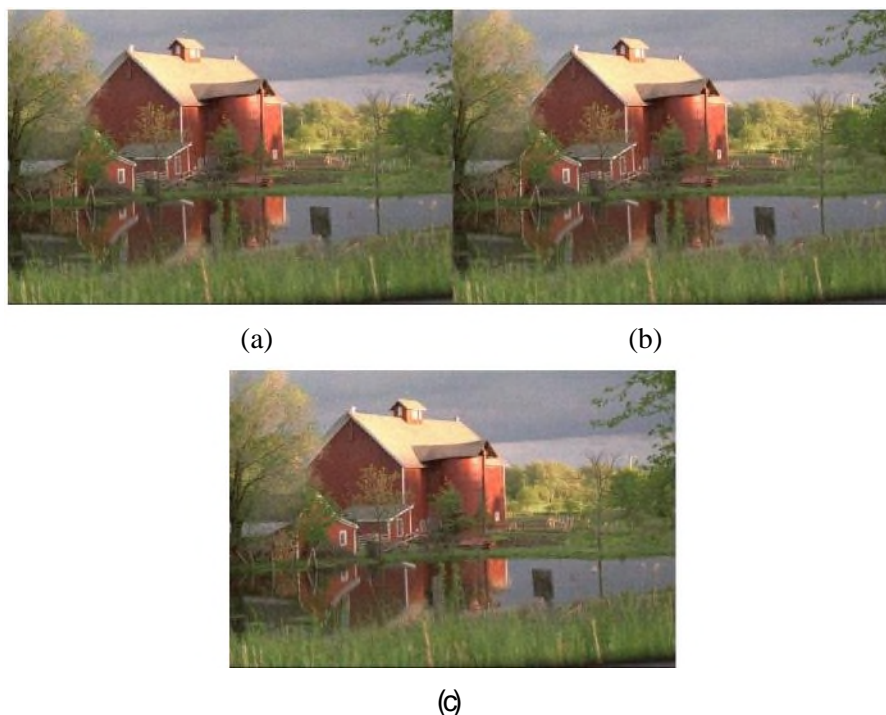
**Figure 6. Kodak Dataset**

The proposed noise model was tested on 20 Kodak dataset (1-9, 11, 13-23). Their images are shown in Figure. 6. Table 1 shows PSNR results for two conventional models and the proposed model. Note that assumption 2 is not applicable as  $\{(k_0, k_1)=(0,0), (25,0), (25,0.1), (25,0.2)\}$  parameter set is not available for comparison.

Figure 7 and 8 show demosaicked images on generated noisy CFA images by Assumptions 1 and 2, and the proposed model. Applied noise level is 10 ( $\sigma=20$ ).



**Figure 7. Demosaicked Images (#4) on Generated Noisy CFA Images: (a) Assumption 1, (b) Assumption 2, and (c) Proposed Noise Model**

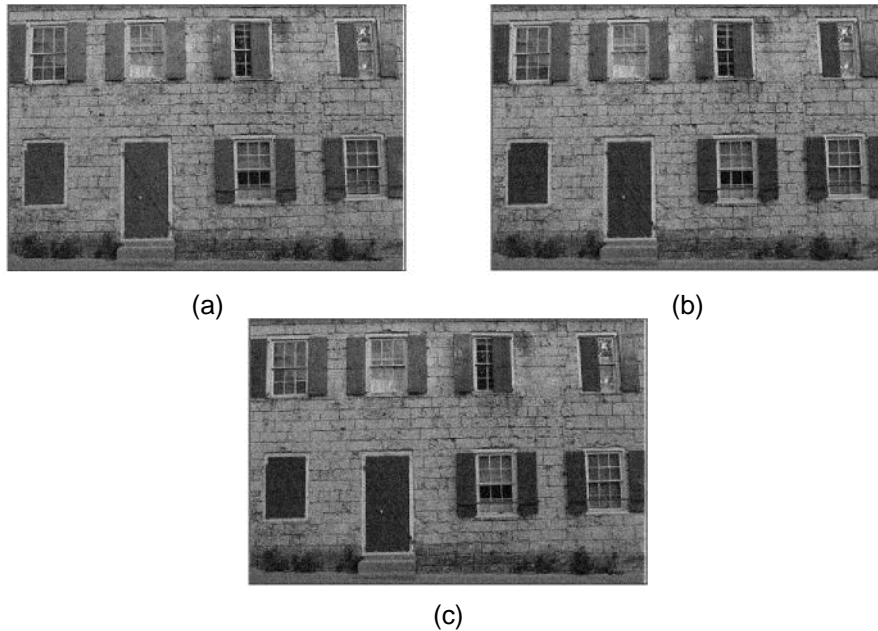


**Figure 8. Demosaicked Images (#22) on Generated Noisy CFA Images:  
(a) Assumption 1, (b) Assumption 2, and (c) Proposed Noise Model**

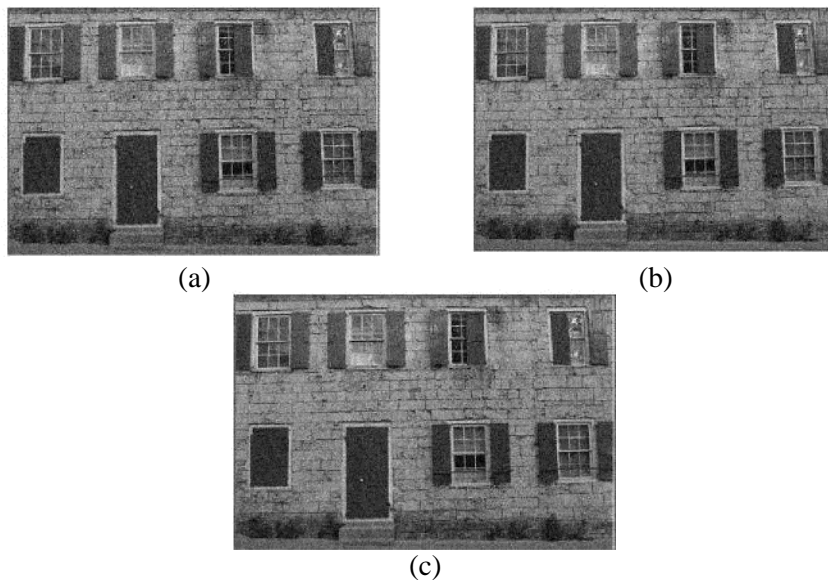
**Table 1. PSNR Results for Two Conventional Methods and the Proposed Method for 20 Kodak Images**

Image number	Assumption 1	Assumption 3	Proposed model
1	36.211	36.211	36.026
2	23.061	23.210	22.693
3	14.245	14.349	13.892
4	30.097	30.637	29.916
5	19.683	19.637	19.700
7	28.965	29.073	29.000
8	43.808	43.808	43.808
9	34.777	34.030	34.265
11	19.876	20.046	19.011
13	28.894	28.336	29.259
14	21.213	21.285	21.427
15	20.706	20.830	20.637
16	43.808	43.808	43.808
17	34.777	34.030	34.146
18	29.146	29.336	28.429
19	27.706	27.814	27.787
20	23.089	23.229	22.980
21	36.026	36.211	36.606
22	49.828	49.828	49.828
23	27.653	27.601	27.925
Average	29.678	29.666	29.557

Figure 9 shows generated noisy CFA images with various RGB patterns. Figure 9(a) uses RRGB pattern, therefore twice more red information are given for CFA images. In the same matter, Figures 9(b) and (c) uses RGGB and RGBB patterns. Figure 10 shows generated noisy CFA images on RGGB pattern. There scenarios were used: Assumption 1 with  $\sigma=10$ , Assumption 3 with  $\sigma=10$ , and the proposed method. As we can see, the proposed noise model reflected the most natural images when it compared with other images.



**Figure 9. Generated Noisy CFA Images: (a) RRGB, (b) RGGB, and (c) RGBB**



**Figure 10. Generated Noisy CFA Images Using RGGB Pattern: (a) Assumption 1 ( $\sigma=10$ ), (b) Assumption 3 ( $\sigma=10$ ), and (c) Proposed Noise Model**



## 5. Conclusions

In this paper, we studied a new noise model for conventional Bayer color filter array. Performance of three color patterns were evaluated and compared. Conventional noise models do not consider some important properties such as white balance, gamma and tone correction. The proposed noise model suggested using above issues. Experimental results revealed that the proposed noise model is more acceptable to noisy demosaicking.

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## Footnote

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