# Demosaicking algorithms for RGBW color filter arrays

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## Abstract

*Digital cameras capture images through color filter array patterns and reconstruct the images using an appropriate demosaicking algorithm. CFAs usually contain three primary color filters. Since the panchromatic/ white filter receives less noise compared to the Red, Green and Blue filters, the CFA also can have additional white filters to reduce the noise impact on the reconstructed color image. Digital cameras only receive one color component at each pixel location through the CFA and the other unknown color components will be estimated using the demosaicking algorithm.*

*In this paper, the RGBW-Bayer pattern has been studied, and appropriate adaptive and non-adaptive demosaicking algorithms have been provided for it. Also an optimized way will be presented to estimate the panchromatic filter output using red, green and blue color information. A modified demosaicking algorithm also has been presented for a new RGBW CFA [1], and the comparison between these two RGBW CFAs and the RGBw-Kodak [9] CFA has been provided. The proposed algorithms have been tested on the Kodak sample images.*


## Introduction

Digital camera sensors are usually covered by different CFA filters and receive the color information passed through a CFA pattern. The CFAs mostly contain three primary color filters (red, green and blue), and each CFA sensor captures only one primary color component. The most common CFA is Bayer containing two green pixels, one red and one blue [2]. Since the amount of received noise in color filters is more than non-color filters, some other modified CFAs contain panchromatic/ white filters as well. The simplest four-color CFA is RGBW-Bayer.

Each R, G and B CFA pixel only captures one of primary color component and white filters pass all three color components. The value of missing color components will be estimated with an appropriate demosaicking algorithm. A basic demosaicking scheme relies on bilinear interpolation of neighboring pixels color information [3]. Since both demosaicking algorithms and CFA design are important to restore an optimal image, we are presenting adaptive and non-adaptive demosaicking algorithm for three different RGBW CFAs.

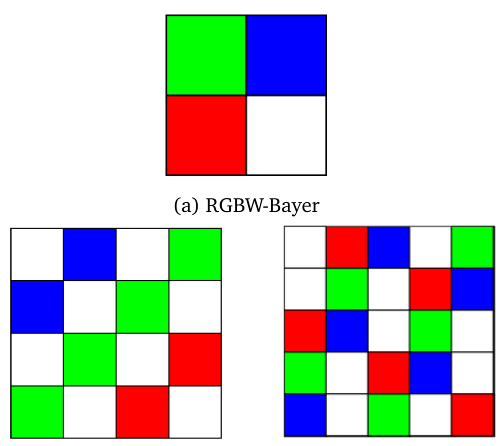
In last decade, it has been demonstrated that the luma and chroma components are reasonably isolated in the frequency domain. Hence, demosaicking algorithms using a frequency domain representation became more competitive, and many demosaicking methods on the RGB-Bayer pattern have been discussed in the frequency domain. One of the most successful algorithm has been presented in [4] using Least Squares Optimization and an adaptive scheme to reduce the overlap between luma and chroma components.

Different four channel CFAs have been studied and compared using the interpolation method in [5]. A new demosaicking algorithm based on [6] will be provided for RGBW-Bayer, RGBW-Kodak and a $5 \times 5$ RGBW [1] in this paper. Due to the specific structure of these CFAs and the number of different color filters, these three CFAs have been compared in this paper.

The Kodak-RGBW pattern has a large number of white filters and its demosaicking algorithm has been discussed in [9]. We have developed a new demosaicking algorithm using the RGBW-Bayer pattern as a four-channel color filter array to enhance the quality of the display and reduce the noise in the sense of human vision perception [5]. The additional filter array is spectrally nonselective and isolate luma and chroma information. The $5 \times 5$ RGBW CFA has been proposed in [1] and the demosaicking algorithm presented in [4] has been implemented on it. We are presenting some improvement on the result of the demosaicking images using this pattern with the demosaicking algorithm.

## Method

In this research, three different RGBW patterns have been studied and an appropriate demosaicking algorithm has been proposed for each CFA. Figure 1 shows the RGBW-Bayer, RGBW-Kodak and a new proposed RGBW CFA in [1].The RGBW-Bayer contains four pixels; it is similar to the RGB-Bayer, where one of the green filters has been replaced with a white pixel. The RGBW-Kodak pattern has 16 pixels, where half of the filters are white and the number of green pixels is as twice as large as for red or blue filters. The third CFA is a $5 \times 5$ template containing 10 white pixels and an equal number of red, green and blue filters. The basic theory of the proposed demosaicking algorithm is based on [6] and has been adapted for those RGBW CFAs. The proposed demosaicking algorithm for RGBW-Kodak has been fully described in [9].



(a) RGBW-Bayer

(b) RGBW-Kodak (c) RGBW($5 \times 5$)[1]

Figure 1: RGBW CFA patterns

The development for the three CFA patterns is presented in parallel. For each pattern, the CFA signal is sampled on lattice $\Lambda = Z^2$ with reciprocal lattice $\Lambda^* = Z^2$. The periodicity of the lattice covers all pixels in one period. The periodicity lattice and corresponding reciprocal lattice are given by:

$$V_\Gamma = \begin{bmatrix} 2 & 0 \\ 0 & 2 \end{bmatrix}, V_{\Gamma^*} = \begin{bmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{bmatrix} \text{for RGBW-Bayer} \quad (1)$$

$$V_\Gamma = \begin{bmatrix} 4 & 0 \\ 0 & 4 \end{bmatrix}, V_{\Gamma^*} = \begin{bmatrix} \frac{1}{4} & 0 \\ 0 & \frac{1}{4} \end{bmatrix} \text{for RGBW-Kodak} \quad (2)$$

$$V_\Gamma = \begin{bmatrix} 2 & -1 \\ 1 & 2 \end{bmatrix}, V_{\Gamma^*} = \begin{bmatrix} \frac{2}{5} & \frac{-1}{5} \\ \frac{1}{5} & \frac{2}{5} \end{bmatrix} \text{for RGBW}(5\times 5) \quad (3)$$

Using the mentioned lattices for each CFA, we can model the CFA signal as a sum of luma and chrominace components. The demosaicking model described in [6] has been used and modified here.

$$f_{CFA}[\mathbf{x}] = \sum_{i=1}^{K} q_i[\mathbf{x}] \exp(j2\pi(\mathbf{x}\cdot\mathbf{d}_i))), \quad (4)$$

$$K = \text{number of samples in each CFA pattern} \quad (5)$$

According to [4], $\mathbf{b}_i$ refers to the columns of matrix $\boldsymbol{B}$ which gives the coset representative of $\Gamma$ in $\Lambda$. Also $\mathbf{d}_i$ refers to the columns of matrix $\boldsymbol{D}$ and they are coset representatives of $\Lambda^*$ in $\Gamma^*$.

$$\boldsymbol{B}_{Bayer} = \begin{bmatrix} 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \end{bmatrix}, \quad (6)$$

$$\boldsymbol{B}_{Kodak} = \begin{bmatrix} 0 & 1 & 2 & 3 & 0 & 1 & 2 & 3 & 0 & 1 & 2 & 3 & 0 & 1 & 2 & 3 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 2 & 2 & 2 & 2 & 3 & 3 & 3 & 3 \end{bmatrix} \quad (7)$$

$$\boldsymbol{B}_{(RGBW5\times5)} = \begin{bmatrix} 0 & 1 & 2 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix}, \quad (8)$$

The matrix $\boldsymbol{D}$ is a $2\times K$ matrix where $K$ is the number of components in one period of the lattice, which is equal to 4 in RGBW-Bayer, 16 for the RGBW-Kodak. For the RGBW [1] pattern, we choose a small repeated pattern containing five color filter as a basic RGBW$(5\times5)$ unit cell, and the number of components for this pattern will decrease to 5. Since, the period of this CFA decrease from 25 pixels to 5 pixels, the calculation will be less complex.

$$\boldsymbol{D}_{Bayer} = \frac{1}{2} \times \begin{bmatrix} 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \end{bmatrix}, \quad (9)$$

$$\boldsymbol{D}_{Kodak} = \frac{1}{4} \times \begin{bmatrix} 0 & 1 & -1 & 0 & 0 & 1 & -1 & 1 & -1 & 2 & 0 & 2 & -1 & 2 & 1 & 2 \\ 0 & 0 & 0 & 1 & -1 & 1 & -1 & -1 & 1 & 0 & 2 & -1 & 2 & 1 & 2 & 2 \end{bmatrix} \quad (10)$$

$$\boldsymbol{D}_{(RGBW5\times5)} = \frac{1}{5} \times \begin{bmatrix} 0 & 2 & -2 & -1 & 1 \\ 0 & 1 & -1 & 2 & -2 \end{bmatrix}, \quad (11)$$

The luma and chroma components can be extracted from the CFA image, so we can calculate the matrix $\boldsymbol{M}$ using the following equation.

$$\boldsymbol{q}[\mathbf{x}] = \boldsymbol{M}\boldsymbol{f}[\mathbf{x}] \quad (12)$$

$$\boldsymbol{f} = \begin{bmatrix} f_1, & f_2, & f_3, & f_4 \end{bmatrix}^T \quad (13)$$

$$\boldsymbol{q} = \begin{bmatrix} q_1, & q_2, & \dots & , & q_K \end{bmatrix}^T$$

$$K = \text{number of samples in each CFA pattern} \quad (14)$$

The calculated matrices $\boldsymbol{M}$ for each CFA are as follow.

$$\boldsymbol{M}_{Bayer} = \begin{bmatrix} 0.25 & 0.25 & 0.25 & 0.25 \\ -0.25 & 0.25 & 0.25 & -0.25 \\ 0.25 & 0.25 & -0.25 & -0.25 \\ -0.25 & 0.25 & -0.25 & 0.25 \end{bmatrix} \quad (15)$$

$$\boldsymbol{M}_{Kodak} = \begin{bmatrix} 0.125 & 0.25 & 0.125 & 0.5 \\ -0.0625+0.0625i & 0 & 0.0625-0.0625i & 0 \\ -0.0625-0.0625i & 0 & 0.0625+0.0625i & 0 \\ 0.0625-0.0625i & 0 & -0.0625+0.0625i & 0 \\ +0.0625+0.0625i & 0 & -0.0625-0.0625i & 0 \\ 0.125 & -0.25 & 0.125 & 0 \\ -0.125 & 0.25 & -0.125 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -0.0625+0.0625i & 0 & 0.0625-0.0625i & 0 \\ +0.0625-0.0625i & 0 & -0.0625+0.0625i & 0 \\ -0.0625-0.0625i & 0 & +0.0625+0.0625i & 0 \\ +0.0625+0.0625i & 0 & -0.0625-0.0625i & 0 \\ -0.125 & -0.25 & -0.125 & 0.5 \end{bmatrix} \quad (16)$$

$$\boldsymbol{M}_{(RGBW5\times5)} = \begin{bmatrix} 0.2 & 0.2 & 0.2 & 0.4 \\ -0.1618-0.1176i & -0.1618+0.1176i & 0.0618+0.1902i & 0.2618-0.1902i \\ -0.1618+0.1176i & -0.1618-0.1176i & 0.0618-0.1902i & 0.2618+0.1902i \\ 0.0618+0.1902i & 0.0618-0.1902i & -0.1618+0.1176i & 0.0382-0.1176i \\ 0.0618-0.1902i & 0.0618+0.1902i & -0.1618+0.1176i & 0.0382-0.1176i \end{bmatrix} \quad (17)$$

The matrix $\boldsymbol{J}$ is defining the four input channels: R, G, B and W, while each column of the matrix represents one of the colors in this pattern. Since the regular cameras on the market usually have a three- channel CFA, we assumed to have three-channel CFA camera input and simulate the values of the white filter in the CFA image. Ideally the white filter should pass all three colors and does not absorb any color spectrum. So the value of the white pixels in CFA image can be estimated as the summation of R, G and B divided by three. The value that has been captured by the white filter usually contain less noise compared the other three color filters and the optimized results of this study can be used for noise reduction purposes in the future.

$$J_{Bayer} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}^T \quad (18)$$

$$J_{Kodak} = \begin{bmatrix} 0&0&0&1&0&0&1&0&0&0&0&0&0&0&0&0 \\ 0&1&0&0&1&0&0&0&0&0&0&1&0&0&1&0 \\ 0&0&0&0&0&0&0&0&0&1&0&0&1&0&0&0 \\ 1&0&1&0&0&1&0&1&1&0&1&0&0&1&0&1 \end{bmatrix}^T$$

$$J_{RGBW5\times5} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix}^T \quad (20)$$

$$W = \frac{1}{3}(R+B+G) \quad (21)$$

Using equation 21 we can measure white pixels ($W$) using the red, green and blue color components. In the frequency domain, the Fourier transform of the CFA signal is given by:

$$F_{CFA}(\mathbf{u}) = \sum_{i=1}^{K} Q_i(\mathbf{u}-\mathbf{d}_i) \quad \text{Where} \quad Q_i(\mathbf{u}) \triangleq \mathscr{F}\{q_i[\mathbf{x}]\} \quad (22)$$

The chroma components are extracted with bandpass filters centered at the frequencies $\mathbf{d}_i$. The next step in the non-adaptive demosaicking algorithm is reconstructing the full RGB color image using the pseudoinverse matrix $\boldsymbol{M}^\dagger$ and the extracted chromas using equation 13. Figure 2 shows the position of extracted components in one unit cell of $\Lambda^*$ for each CFA. Since we cannot fully extract the chromas close to the luma, those chromas can be reconstructed using the rest of the components. Since we are finding the value of white filters using equation 21, the relation between q components and RGBW-Bayer components can be recalculated as follows:

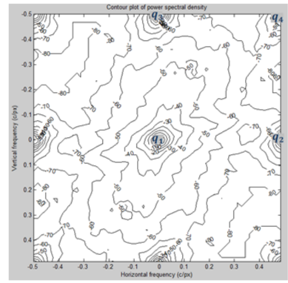
$$q_2 = \frac{f_1}{4} + \frac{f_2}{4} + \frac{f_3}{4} + \frac{f_4}{4} \quad (23)$$

$$f_4 = \frac{1}{3} \times (f_1 + f_2 + f_3) \quad (24)$$

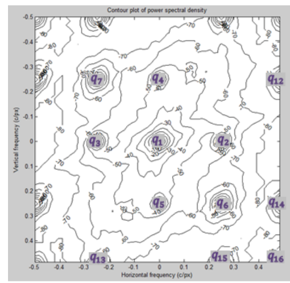
$$q_2 = -\frac{f_1}{3} + \frac{f_2}{6} + \frac{f_3}{6} \quad (25)$$

The same method has been applied for calculating the chroma components for the non-adaptive demosaicking algorithm using the RGBW($5\times5$) patterns as well. In RGBW-Kodak, we can extract one of the chromas which is further to the luma and reconstruct a set of chromas closer to the luma using matrix $\boldsymbol{M}$ to avoid overlapping effect. More details about both adaptive and Non-adaptive method are in [9].

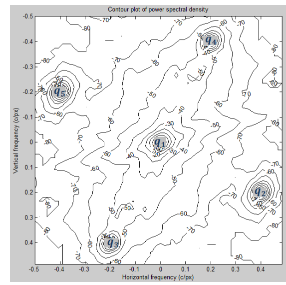
Due to the similarity between the chromas in RGBW-Bayer and RGBW($5\times5$), all of the chroma components in both adaptive and non-adaptive algorithm have been extracted using one



(a) RGBW-Bayer



(b) RGBW-Kodak



(c) RGBW($5\times5$)

Figure 2: Luma- Chroma position in one unit cell

Gaussian filter. Since we need either $q_2$ or $q_3$ for reconstructing color image in RGBW-Bayer, as has been discussed in [4] for RGB-Bayer, we assign weight to these chromas adaptively by measuring the overlapping effect around $q_2$ and $q_3$, and the more isolated chroma receive more weight. The following equation shows the weighting scheme to optimize the chroma and luma reconstruction. The luma will be estimated by subtracting all chromas from CFA image and will be updated with new estimated chromas afterward. The $f_1(x)$, $f_2(x)$ and $f_3(x)$ is derived as follows using $q_1$, $q_2$ and $q_4$:

$$f_{1A}(x) = q_1(x) - 2q_2(x) \quad (26)$$

$$f_{2A}(x) = q_1(x) + 2q_4(x) \quad (27)$$

$$f_{3A}(x) = q_1(x) + 2q_2(x) - 2q_4(x) \quad (28)$$

and using $q_1$, $q_3$ and $q_4$ we have:

$$f_{1B}(x) = q_1(x) + 2q_3(x) - 2q_4(x) \quad (29)$$

$$f_{2B}(x) = q_1(x) + 2q_4(x) \quad (30)$$

$$f_{3B}(x) = q_1(x) - 2q_3(x) \quad (31)$$

In both scenarios,$f_2(x)$ is same. By assigning wight to $f_A$ and $f_B$, the following equation will be derived.

$$f_1(x) = q_1(x) + 2w(x)q_2(x) + 2(1-w(x))(q_3(x) - q_4(x)) \quad (32)$$

$$f_1(x) = q_1(x) + 2(1-w(x))q_3(x) + 2w(x)(q_2(x) - q_4(x)) \quad (33)$$

So we can reconstruct the $q_2$ and $q_3$ as follows:

$$q_2(x) = (w(x)) \times q_2(x) + (1-w(x)) \times (q_4(x) - q_3(x)) \quad (34)$$

$$q_3(x) = (1-w(x)) \times q_3(x) + (w(x)) \times (q_4(x) - q_3(x)) \quad (35)$$

### *Optimizing white filter estimation*

The method described above is based on equation 21. We optimized the white color component calculation assuming that there is a linear relationship between white component and the three primary color components (red, green, blue). The following method describes the closest way that we can linearly model white color components similar to the digital cameras. Figure 3 shows a typical non-normalized responsivity of red, green, blue and white filter spectral responses, according to the VEML6040 sensor developed by Vishay company [10].

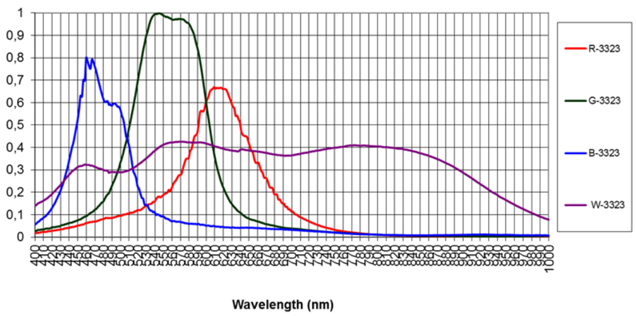



Figure 3: Spectral response of VEML6040 sensor(400nm-1000nm)

We normalized the values of red, green, blue and white components by multiplying them to the spectrum of $D65$, as a constant power density spectrum, on a specific range of wavelength. Then using a database of typical spectral densities of light, we can calculate and minimize the error between the real white components and the calculated one. Using the Macbeth color checker database [11], we calculate and normalized the values of red ($C_R$), green ($C_G$), blue ($C_B$) and white ($C_W$) for each data. Using the Quadratic programming we will minimize the error subject to $a_R + a_B + a_G = 1$.

$$Error = \sum_{i=1}^{N} (C_{Wi} - (a_R C_{Ri} + a_G C_{Gi} + a_B C_{Bi}))^2 \tag{36}$$

$N =$ number of samples in the database

The calculated $a_R$, $a_B$ and $a_G$ will be replaced in equation 21 as coefficients for red, green and blue components. The calculated values are $a_R = 0.2936$, $a_G = 0.4905$ and $a_B = 0.2159$. So, the white filter values in the CFA have been updated using equation 37, and the adaptive demosaicking algorithm for RGBW-Bayer pattern has been designed based on the new white values. We can apply the designed adaptive demosaicking algorithm based on equation 21 on the calculated CFA using equation 37, and the PSNR results will be less than the updated adaptive demosaicking algorithm using equation 37, as we can see in the table 1. The table 1 shows the comparison between the total PSNR values over the 24 Kodak images using the ideal estimation for white value using equation 21 and the real estimation for white filters using equation 37. The estimated values for white filters in using equation 37 show the closest white values to the received values in white filters in digital cameras. The results show that the PSNR values improve using the updated adaptive demosaicking algorithm.

$$W = 0.2936(R) + 0.4905(G) + 0.2159(B) \tag{37}$$

| Image number in dataset | (a) | (b) | (c) |
|---|---|---|---|
| 1 | 37.90 | 36.61 | 38.02 |
| 6 | 43.64 | 36.21 | 43.83 |
| 8 | 34.92 | 34.55 | 34.97 |
| 13 | 34.87 | 33.49 | 35.09 |
| 16 | 43.80 | 40.93 | 43.99 |
| 19 | 40.13 | 37.88 | 40.21 |
| 21 | 38.65 | 37.87 | 38.72 |
| 24 | 39.36 | 37.71 | 39.39 |
| Average over 24 images | 39.49 | 36.81 | 39.56 |

Table 1: PSNR for some sample images and average total PSNR over 24 images. (a) Results of applying adaptive demosaicking method designed using equation 21 for the CFA modeled using equation 21, (b) Results of applying adaptive demosaicking method designed using equation 21 for the CFA modeled using equation 37, (c) Results of applying adaptive demosaicking method designed using equation 37 for the CFA modeled using equation 37

## Results and discussion

Since the white filters in CFAs reduce the amount of received noise, we decided to develop a demosaicking scheme for RGBW CFAs in this research. Three different four channel CFA have been compared and the demosaicking algorithm has been developed for RGBW-Bayer and RGBW($5 \times 5$). The Kodak data set is used to evaluate and compare the results. Table 2 shows the signal to noise ratio comparison between non-adaptive demosaicking algorithm for each CFA as well as the results of PSNR of the previous work on RGBW $5 \times 5$ [1] for eight sample images with more details and the average over 24 Kodak dataset. Table 3 illustrates the PSNR comparison between adaptive demosaicking results for RGBW-Bayer and RGBW-Kodak [9] for the same sample images. The results have been compared with the results of Least Square method on the RGB-Bayer [3]. The results of table 2 shows the non-adaptive demosaicking method that we proposed for RGBW($5 \times 5$) improved the PSNR comparing to the method in [1]. Also the result of non-adaptive method using RGBW-Bayer is also working slightly better than the previous method in most of the cases.

The table 3 provides some improvement on the proposed adaptive demosaicking algorithm using the RGBW-Bayer comparing to the adaptive algorithm using RGBW-Kodak and the LS method results on RGB-Bayer template. Usually adaptive demosaicking method reconstruct more isolated chroma and luma signals and works better than non-adaptive methods, as we can see in the reconstructed images. Figure 4 shows that, among non-adaptive methods, the RGBW($5 \times 5$) is more successful to estimate colors correctly while RGBW-Bayer reconstruct the edges and image details better. Comparing adaptive algorithms, the RGBW-Kodak is fully estimates the colors and the proposed weighted algorithm for RGBW-Bayer reconstructs the image details better while it contains some false color. We

(a) Original image

(b) Non-adaptive RGBW-Kodak

(c) RGBW CFA(5 × 5)

(d) Adaptive RGBW-Kodak

(e) Non-Adaptive RGBW-Bayer

(f) Adaptive RGBW-Bayer

(g) Least Square RGB-Bayer [3]

Figure 4: Comparison between The adaptive and non-adaptive demosaicking method for different four channel CFAs

can conclude that the CFA templates with more white filters estimate less false colors and an appropriate adaptive demosaicking algorithm is needed to restore the edges perfectly.

## Conclusion

In this paper, we reviewed three different four channel CFA patterns containing white filter. We presented the non-adaptive and adaptive algorithms for RGBW-Bayer. We also, implemented our non-adaptive demosaicking algorithm for the RGBW-5x5, and the results shows some improvement comparing to the previous work on this pattern. The results of these RGBW-CFAs have been compared with the previous work using RGBW-Kodak pattern.

| Image number in dataset | Bayer-RGBW (Non-Adaptive demosaicking) | Kodak-RGBW (Non-Adaptive demosaicking) | RGBW(5 × 5) proposed Non-Adaptive demosaicking) | RGBW(5 × 5) reconstructed in [1] using Dubois's Method |
|---|---|---|---|---|
| 1 | 36.1 | 27.1 | 36.6 | 35.2 |
| 6 | 39.2 | 29.6 | 38.9 | 36.6 |
| 8 | 34.9 | 30.1 | 34.3 | 33.3 |
| 13 | 35.1 | 27.5 | 33.0 | 30.9 |
| 16 | 40.3 | 33.0 | 41.0 | 39.6 |
| 19 | 37.1 | 28.5 | 38.6 | 37.5 |
| 21 | 37.2 | 30.0 | 37.3 | 36.1 |
| 24 | 37.1 | 33.5 | 35.3 | 31.9 |
| Average over 24 images | 37.1 | 31.3 | 36.9 | 35.4 |

Table 2: PSNR of some sample images for Non-Adaptive demosaicking method using different RGBW patterns and the average PSNR over 24 Kodak images

| Image number in dataset | Bayer-RGBW (Adaptive demosaicking) | Kodak-RGBW (Adaptive demosaicking) | RGB-Bayer (LSLCD method)[4] |
|---|---|---|---|
| 1 | 37.9 | 36.3 | 37.9 |
| 6 | 43.6 | 38.6 | 39.9 |
| 8 | 34.9 | 35.3 | 35.3 |
| 13 | 34.8 | 33.0 | 34.2 |
| 16 | 43.8 | 41.3 | 43.6 |
| 19 | 40.1 | 38.1 | 40.5 |
| 21 | 38.6 | 36.7 | 38.7 |
| 24 | 39.3 | 34.0 | 35.3 |
| Average over 24 images | 39.4 | 36.3 | 39.8 |

Table 3: Comparison between the PSNR of some sample images for Adaptive demosaicking method usinf RGBW CFAs and Least Square method using RGB-Bayer

The reviewed patterns receive more light because of the white color filters, and reconstruct colors more accurately than the three color CFAs [7]. The adaptive algorithm for RGBW-Bayer improved the quality of the image. The results can be used for noise reduction stage in future work.
Furthermore, in this research, we present a more realistic model for the white filter using optimization method. Ideally, the panchromatic/white filter, receives equal amount of red, green and blue in each pixel. The demosaicking method for RGBW-Bayer have been proposed and compared in both cases.

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