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Two Stage Demosaicing Algorithm for Color Filter Arrays

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Abstract

This paper proposes an efficient two stage demosaicing method to interpolate color filter array images. The proposed method based on the edge sensing technique improves the interpolation performance by adopting the color difference model for a green channel as well as a red/blue channel. In particular, the green channel interpolation method with a new concept includes the gradient operator, which uses the total amount of slope changes in adjacent color information, and the missing green color estimation, which uses Approximated Directional Line Averages. Comparing with various comparative experiments between the conventional results and the proposed ones, the performances of the proposed method in this paper outperform to existing algorithms in terms of visual performance both in numerical and visual aspects. Our method of demosaicing improves the standard performance by8.927dB on the average in comparison of other methods in MSE(Mean square Error).

Keywords: *Color difference, Demosaicing, CFA interpolation.*

1. Introduction

As digital imaging devices such as digital cameras with a single image sensor have been popular, a lot of researches to improve image quality obtained by a single image sensor have been actively performed. The single image sensor only takes the signals filtered by the color filter array (CFA). The CFA is an array pattern where three filters, each of which enables only one color of red(R), green(G), and blue(B) to be penetrated into a pixel, are combined and crossed. The Bayer's pattern is the most popular among CFA patterns [1]. The Bayer's pattern is composed of 50 percent of green color filters, 25 percent of red color filters and 25 percent of blue color filters. The images obtained through the digital image process have only one color per pixel, which is called as CFA data. The CFA images are grayscale images that have one color per pixel. Therefore, the grayscale images must go through the CFA interpolation or the demosaicing process to be reconstructed as full color images.

A lot of studies have been performed for several years and a variety of methods have been introduced. The simplest method among them is the bilinear interpolation, which estimates missing color components by averaging the values of the adjacent color pixels with the same color as the color to be interpolated. This method is so simple to implement, but a lot of color artifacts are shown on the edge region or texture region of a restored image, which is a shortcoming of the method. The edge-sensing based method is adopted to overcome such shortcomings. This paper proposed a very efficient demosaicing method based on the edge-sensing method and the color difference model. This method provides green color estimation that uses not only correlation between local channel averages but also the gradient operator that uses the total amount of slope changes in the local region to select interpolation direction. The method proposed in this paper improves interpolation performance of green channel so that overall performance of demosaicing is improved. This paper is composed as follows. Section 2 discusses the principles and problems of the interpolation methods based on the edge-sensing or the color-difference model and describes the principles and features of the proposed method in detail. Section 3 propose TDSA(Two stage Demosaicing Algorithm) and section 4 shows a variety of performance test results. Finally, Section 4 includes the conclusion of this paper.

2. Demosaicing Methods

Most CFA interpolation methods interpolate green channels first and red/blue channels later. In addition, the edge-sensing methods determine interpolation direction by performing a gradient test at the location of the missing green color before the green color is interpolated. In the edge sensing based methods, the gradient operator is a very important factor to affect visual quality of a reconstructed image. In addition, since the green channel interpolation preceding the red/blue channel interpolation has a remarkable influence on overall performance of demosaicing as well as other channel interpolation for other colors, many demosaicing techniques are more significantly focused on improvement of the green channel interpolation performance. Suppose that S and T of the Bayer's CFA data shown in the Fig. 1 represent red (or blue) color and blue (or red) color, respectively. The AICG[4]uses the second order derivatives of red/blue information in the local region so that the capability to preserve the edge or texture region is more improved than the bilinear interpolation [5] method.

However, the interpolation direction is incorrectly estimated due to no detecting changes in green color. For this problem, it color, use the average of adjacent green colors, this method has a defect of blur image. The ACPI [4] more accurately estimates the missing green color by adding the average of adjacent green colors to the correction value of neighboring S colors in the location to be interpolated.

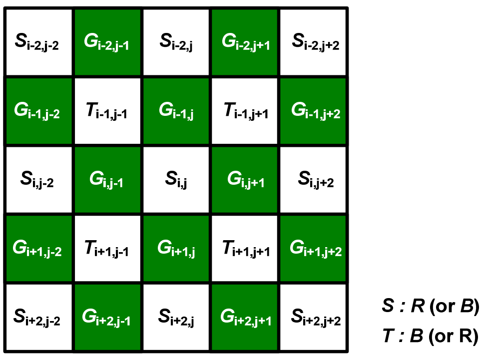


Figure 1. Bayer CFA Pattern

To compute a gradient in a direction the first order derivatives of green colors are used for AICG whereas both the second order derivatives of S colors and the first order derivatives of G colors are used for ACIP and PCI[3][4]. Such methods sometimes estimate a wrong interpolation direction because they estimate gradients of green colors to be flat and gradients of S colors to be lower than those of actual ones when S colors are in a straight line although there are great differences of gradients between green colors and S colors in a certain test direction.

3. Two Stage Demosaicing Algorithm

The types of demosaicing algorithm can be broadly categorized into two types according to the number of processing per channel. One category is known as single process interpolation technique, which outputs full-color image via one time demosaicing of each channel. The other is referred to as iterative demosaicing technique, which undergoes more than one updating process for the image resulting from a single demosaicing. The demosaicing algorithm proposed in this paper is a two-stage demosaicing algorithm, which updates in a single process the image resulting from an initial interpolation. Stage 1 interpolates G channel from CFA image and uses the interpolated G channel and uninterpolated channels R and B and interpolates channels R and B. The result of stage 1 processing of CFA image is a full-color image. Next, the initial green channel interpolation of stage 1 and the green channel updating of stage 2 in TSDA both include the process of sorting the interpolation direction. However, the former, as shown in Fig.3., estimates the gradient for 2 directions (horizontal and vertical) in the R or B second stage updates G channel using information on the full-color acquired from stage 1 and afterwards, updates channels R and B. In other words, the proposed demosaicing algorithm is made up of an initial process of interpolation and a process of updating like existing iterative demosaicing algorithm, but the difference is that the proposed algorithm processes the updating process of each channel just once.

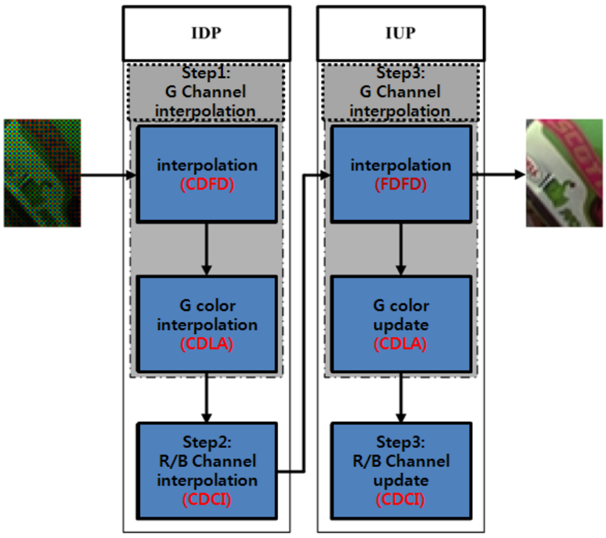


Figure 2. Interpolation process of the proposed TSDA algorithm CFA

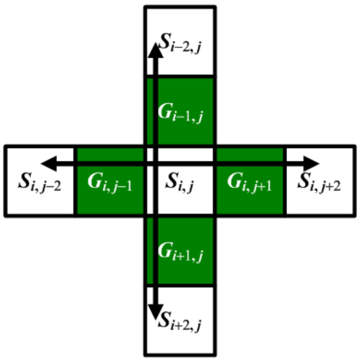


Figure 3. Estimation directions for the CDFD

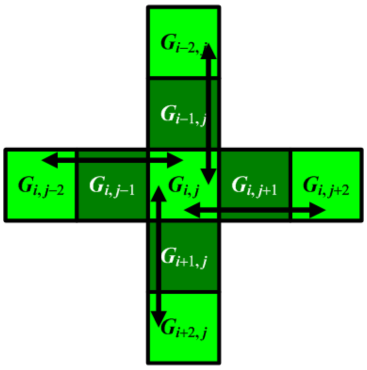


Figure 4. Estimation directions for the FDFD

As shown in Fig.2, TSDA (Two Stage Demosaicing Algorithm) is composed of IDP(Initial Demosaicing Process) and IUP(Image Updating Process). IDP represents as stage 1, and IUP represents as stage 2. That is, the proposed TSDA has no stage where the same process is iteratively processed like POCS[6] or DSA[1] algorithms.

In the stage 1 of the proposed algorithm, IDP has outstanding performance that is comparable to existing single process demosaicing methods, but its performance has been further improved via image updating process. Single process demosaicing methods can also be classified according various forms of approach, the edge-directed method is an approach with outstanding performance for preserving an image's edge which the human visual system most sensitively assimilates. The method which proficiently maintains the correlation between each color channel is the progressive-hue-change. Hence, many demosaicing algorithms combine these two methods and implement image interpolation. The proposed algorithm also combines the edge-directed and progressive-hue-change methods and executes demosaicing. Among the progressive-hue-change methods, the proposed algorithm especially uses the color-difference rule rather than the color-ratio rule.

The initial green channel interpolation of stage 1 and the green channel updating of stage 2 in TSDA both include the process of sorting the interpolation direction. However, In Fig. 3., CDFD(Central Difference Forward Difference) estimates the gradient for 2 directions (horizontal and vertical) in the R or B pixel of CFA image, but FDFD (Forward Difference Forward Difference) estimates the gradient for 4 directions (up, down, left, and right), as shown in Fig. 4. While the CDFD selects 1 direction which has the lower gradient of the 2 directions as interpolation direction, the FDFD selects 2 directions which have the lowest gradients of the 4 directions as interpolation direction. Also, the CDFD interpolates G color using the average regional correlation among the channels in interpolation direction, but the FDFD performs interpolation by averaging the hue signals (R-G or B-G) of 2 pixels that are immediately adjacent toward the two interpolation direction. In the IDP and IUP processes, the R and B channel interpolations both interpolate using CDCI(Color Difference Chrominance Interpolation).

3.1. Initial Demosaicking Process (IDP)

3.1.1. GCI(G Channel Interpolation of CFA): This paper has proposed a new method of gradient operation to enhance the sorting capability of interpolation direction, and the CDFD, which is the proposed gradient operation, uses slope information on the signals of CFA line which lie toward the direction of gradient estimation based on color-difference rule. In Fig. 4 , the square points and circular points in the picture show G and S signals respectively of the original full-color image, and the solid line shows the line of the signals that have been sampled via CFA.

3.1.2. CDLA(Correlation between Directional Line Averages): The color-difference rule is based on the assumption that the difference between the R (or B) channel signal and G channel signal in the regional area is uniform. We induce CDLA [2] from the perspective of color-difference rule for the purpose of evaluating G color in GCI. To explain CDLA, one dimensional color lines of each color channel originally, an S line which is a set of R (or B) signals, G line which is a set of G signals, and CFA line which is a set of CFA samples of an image, are shown in Fig. 4. The directional line average, which is the average value of 5 components centered around x=3 which is a location included in each channel line, has also been represented in Fig. 5. The MS_3, MG_3 and MC_3 each reveals the directional line average of S line, of G line, and of CFA line at the position, x=3 in Fig. 5.

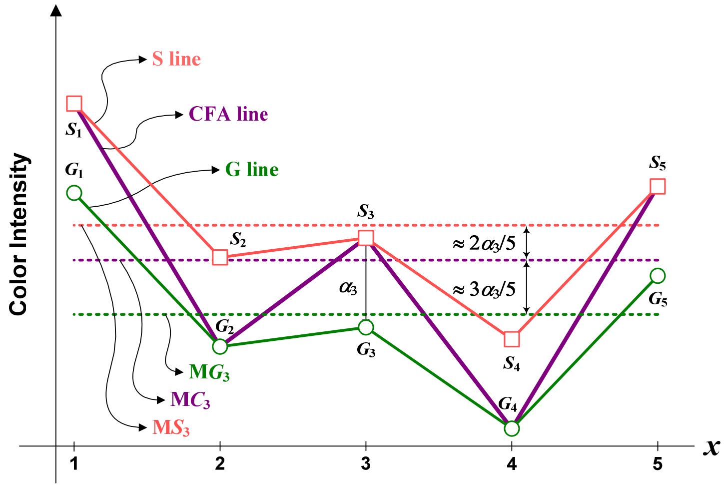


Figure 5. One-dimensional channel lines for the explanation of the correlation between channels

$$\bar{G}_3 \cong S_3 - \frac{\alpha'_3 + \alpha''_3}{2} = S_3 - \frac{5}{4}\left(MS_3 - MC_3\right) - \frac{5}{6}\left(MC_3 - MG_3\right) \tag{1}$$

In equation (1), G_3 denotes G color signal which has been estimated at the location of pixel S_3. In general, The equation interpolates G color components of the location (i,j) using the CDLA as shown in equation (2) .

$$\bar{G}_{i,j} = S_{i,j} - \frac{5}{4}\left(MS_{i,j} - MC_{i,j}\right) - \frac{5}{6}\left(MC_{i,j} - MG_{i,j}\right) \tag{2}$$

Since IDP has good performance when compared to existing single process demosaicing algorithm, it can be utilized as individual demosaicing method. However, to propose a demosaicing algorithm that is more better than existing high performance iterative demosaicing algorithms, In this paper we have proposed an image up dating process in session 2.

3.2. IUP (Image Updating Process)

3.2.1. GCU(G Channel Update): To preserve the edge components of an image in IDP, the interpolation direction has been set and G color has been interpolated in the interpolation direction. This has used the characteristics of human visual system that are sensitive to the edge components of an image. Hence, we has placed its basis in edge-directed even for G channel updating during the process of image updating. Unlike interpolating CFA image, since the process of image updating uses the already interpolated full-color image, the gradient is computed by using only G colors and not CFA samples which are aligned to the gradient estimation direction. While the CDFD gradient operation sequentially applied the CDFD for the CFA line which is in the estimation direction, the gradient operation in GCU applies the forward difference twice for the G line in the estimation direction. This is because the G channel is interpolated where it has already been interpolated. Also, while gradient estimation was performed only for two directions at vertical and horizontal in GCI, the gradient is estimated for up, down, left, and right directions in GCU. In other words, the FDFD gradient operation for GCU is for each of the G pixels which are in the up, down, left, and right directions using the interpolation location as a reference point. For more explanation about FDFD gradient operation, we have referenced to the G channel pattern that has already been interpolated and as shown in Fig. 4. Those that are marked in bright color in Fig. 4 are G pixels which have been interpolated, and the G pixels that are sampled by CFA have been marked with dark color. If each set of G color signals which are the subject of gradient estimation for up, down, left, and right is $C^{U}_{i,j}$, $C^{Di}_{,j}$, $C^{L}_{i,j}$, $C^{R}_{i,j}$, then each set can be represented as follows.

$$C^{U}_{i,j} = \left\{G_{i-2,j}, G_{i-1,j}, G_{i,j}\right\} \tag{3}$$

$$C^{D}_{i,j} = \left\{G_{i-2,j}, G_{i-1,j}, G_{i,j}\right\} \tag{4}$$

$$C^{L}_{i,j} = \left\{G_{i-2,j}, G_{i-1,j}, G_{i,j}\right\} \tag{5}$$

$$C^{R}_{i,j} = \left\{G_{i-2,j}, G_{i-1,j}, G_{i,j}\right\} \tag{6}$$

$$Slp^{U}_{i,j} = \left\{0, \left(G_{i-1,j} - G_{i-2,j}\right), \left(G_{i,j} - G_{i-1,j}\right), 0\right\} \tag{7}$$

$$Dif^{U}_{i,j} = \left\{\begin{matrix} \left(G_{i-1,j} - G_{i-2,j}\right) \\ , \left(G_{i,j} - G_{i-1,j}\right) - \left(G_{i-1,j} - G_{i-2,j}\right), \\ \left(G_{i,j} - G_{i-1,j}\right) \end{matrix}\right\} \tag{8}$$

To explain using calculation of the gradient for upper G line as shown by formula (3) as an example, $Slp^{U}_{i,j}$ which is a set of slopes for upper G line and $Dif^{U}_{i,j}$ which is a set of the difference of those slopes can be shown as equation (7), equation (8) respectively.

If the size of the slope differences is obtained using formula (8) and those values are added, we can obtain $Grd^{U}_{i,j}$, which is the upper gradient, as shown in equation (9).

Similarly, if $Grd^{D}_{i,j}$, $Grd^{L}_{i,j}$ and $Grd^{R}_{i,j}$ are taken as the gradient for the lower, left, and right directions respectively, then each gradient formula can be represented as follows.

$$\begin{aligned} Grd^{U}_{i,j} &= \left|G_{i-1,j} - G_{i-2,j}\right| \\ &+ \left|\left(G_{i,j} - G_{i-1,j}\right) - \left(G_{i-1,j} - G_{i-2,j}\right)\right| \\ &+ \left|G_{i,j} - G_{i-1,j}\right| \\ &= \left|G_{i-1,j} - G_{i-2,j}\right| \\ &+ \left|2G_{i-1,j} - G_{i,j} - G_{i-2,j}\right| \\ &+ \left|G_{i,j} - G_{i-1,j}\right| \end{aligned} \tag{9}$$

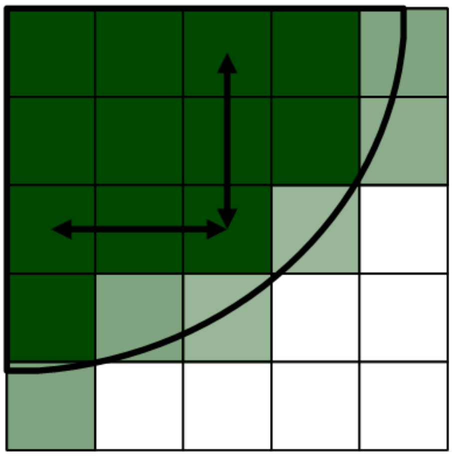
$$\begin{aligned} Grd^{D}_{i,j} &= \left|G_{i+1,j} - G_{i+2,j}\right| \\ &+ \left|2G_{i+1,j} - G_{i,j} - G_{i+2,j}\right| \\ &+ \left|G_{i,j} - G_{i+1,j}\right| \end{aligned} \tag{10}$$

$$\begin{aligned} Grd^{L}_{i,j} &= \left|G_{i,j-1} - G_{i,j-2}\right| \\ &+ \left|2G_{i,j-1} - G_{i,j} - G_{i,j-2}\right| \\ &+ \left|G_{i,j} - G_{i,j-1}\right| \end{aligned} \tag{11}$$

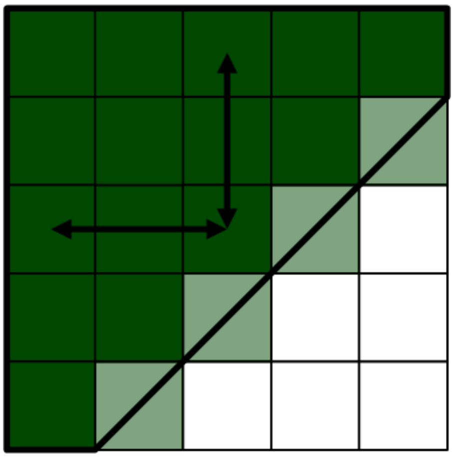
$$\begin{aligned} Grd^{R}_{i,j} &= \left|G_{i,j+1} - G_{i,j+2}\right| \\ &+ \left|2G_{i,j+1} - G_{i,j} - G_{i,j+2}\right| \\ &+ \left|G_{i,j} - G_{i,j+1}\right| \end{aligned} \tag{12}$$

The above equations appear to be similar to the gradient operation of ACPI that has combined the size of secondary difference and the size of primary difference.

However, the gradient of ACPI differs from FDFD in that it has combined the secondary difference of S colors that are adjacent to each other at certain distances with the primary difference of two G colors that are immediately adjacent to the central pixel S. GCU sets as interpolation direction 2 directions out of up, down, left, and right directions and implements interpolation at the applicable 2 directions. While GCI focuses only on preserving the edge in respect to 2 directions by implementing interpolation for vertical, horizontal, or both directions, GCU focuses on preserving detailed image components such as texture and not just on the edge of opposite direction. In the example of GCU, two cases where the boundary area of an object in a sample image is found on the upper left area of the estimation region are represented in Fig. 6 (a) and Fig.6(b). This sample picture has shown the object's region as G signal density (light and shade) of each pixel. Fig.6 (a) has shown the boundary of a circle object, and Fig. 6 (b) has represented the diagonal edge of an object that is sloped obliquely towards the upper right area from the lower left area. Since the density of the signals found on the upper and left area from the central pixel is similar to the density of the central pixel, the two patterns are both appropriate for interpolation of the upper and left area. If interpolation is achieved towards the horizontal or vertical direction passing the central area like in GCI, a significant color error arises because the change to the volume of color signals is large.



(a)



(b)

Figure 6. (a) Boundary of an circle object, and (b) an diagonal edge

Since the GCU already uses full-color image that has already been interpolated, G color is updated utilizing information on pixels that are immediately adjacent to the pixel to be estimated from the two interpolation directions. As a result of acquiring 4 gradients for the pattern is shown in Fig. 4, let the 2 directions with the lowest gradient among them are $O_{i,j}$ and $O'_{i,j}$ respectively. Then, the G colors at the location (i,j) can be updated as shown in the equation (13). $R'_{i,j}$ as shown in equation (13) denotes the difference between G color components and S color components in the pixel immediately adjacent toward interpolation direction of $O_{i,j}$ from the interpolation location of (i,j), and it is the same for $r'_{i,j}$ of equation (14). That is, formula (15) is like adding the average value of the difference of G and S color signals at 2 pixels found in the interpolation direction among up, down, left, and right pixels immediately adjacent to interpolation pixel to the CFA sample signal of the interpolation pixel.

$$\gamma'_{i,j} = \begin{cases} G_{i-1,j} - S_{i-1,j}, & \text{if } O'_{i,j} = U \\ G_{i+1,j} - S_{i+1,j}, & \text{else if } O'_{i,j} = D \\ G_{i,j-1} - S_{i,j-1}, & \text{else if } O'_{i,j} = L \\ G_{i,j+1} - S_{i,j+1}, & \text{else if } O'_{i,j} = R \end{cases} \tag{13}$$

$$\gamma''_{i,j} = \begin{cases} G_{i-1,j} - S_{i-1,j}, & \text{if } O''_{i,j} = U \\ G_{i+1,j} - S_{i+1,j}, & \text{else if } O''_{i,j} = D \\ G_{i,j-1} - S_{i,j-1}, & \text{else if } O''_{i,j} = L \\ G_{i,j+1} - S_{i,j+1}, & \text{else if } O''_{i,j} = R \end{cases} \tag{14}$$

$$\bar{G}_{i,j} = S_{i,j} + \frac{\gamma'_{i,j} + \gamma''_{i,j}}{2} \tag{15}$$

Is, formula (1-15) is like adding the average value of the difference of G and S color signals at 2 pixels found in the interpolation direction among up, down, left, and right pixels immediately adjacent to interpolation pixel to the CFA sample signal of the interpolation pixel.

3.2.2. R/B Channel Update: As described before, R/B channel update has used the CDCI algorithm utilized in the initial R/B channel interpolation.

4. Experiment Result

This section has compared the proposed TSDA algorithm with the proposed IDP as well as with POCS and DSA which are two existing iterative demosaicking algorithms. A comparison of MSE and PSNR performance of each algorithm for the test images has been shown in Table 1,. The test images to be used for the experiment are the 24 images shown in Fig 7.

As sample images of KODAK Photo CD, the present test images are 24 bit lossless images of 512x768 resolution used in many researches on demosaicing http://r0k.us/graphics/kodak/). Prior to the experiment, each test image was downloaded and sampled according to Bayer FA format. Difference image was made for interpolated image and original image for the purpose of performance comparison based on numerical value. After obtaining the mean square error, peak signal-to-noise ratio.

The best performance values in the performance comparison of each test image have been indicated in bold. In MSE performance comparison, POCS showed most outstanding performance in image 10 and image 20, DSA for image 08, image 15, image 16, image 18, image 19, image 22, and image 24, and IDP for image 04, image 12, and image 19. TSDA was most outstanding in the remaining test images and overall average performance. In terms of PSNR comparison, POCS was outstanding in image 10 and image 20, DSA was outstanding in image 08, image 13, image 15, image 16, image 18, image 22, and image 24, and IDP was outstanding in image 04, image 12, and image 19. TSDA was outstanding in the remaining test images and overall average performance.

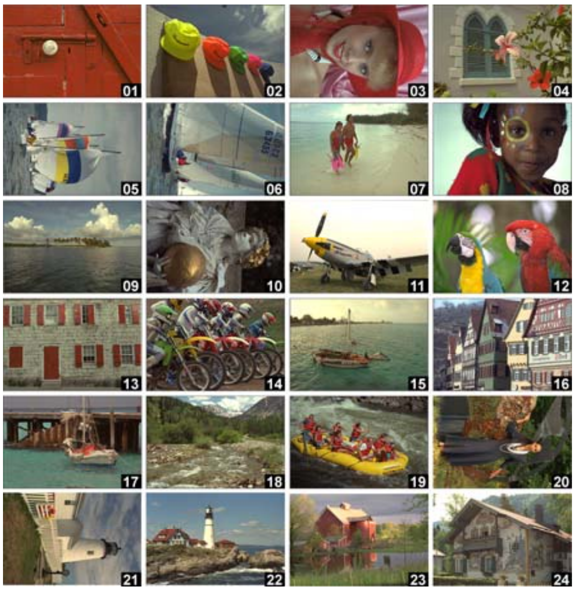


Figure 7. Test images

Table 1. Comparison results of TDSA

PSNR				
Image No.	POCS	DSA	IDP	TSDA
image01	7.391	6.287	5.909	5.582
image02	4.679	4.699	4.428	4.256
image03	6.696	6.561	6.418	6.31
image04	4.6	4.616	3.957	4.111
image05	4.312	4.132	4.545	3.686
image06	4.359	4.316	4.669	4.047
image07	3.64	3.485	3.88	3.225
image08	7.789	7.348	8.348	7.793
image09	4.063	4.305	5.661	3.666
image10	4.797	5.098	6.614	4.987
image11	5.695	5.644	6.673	5.155
image12	4.363	4.27	3.43	4.137
image13	10.204	9.046	18.017	10.919
image14	11.863	14.327	13.74	11.791
image15	8.829	7.811	12.789	8.142
image16	17.839	16.186	25.788	16.475

image17	7.619	8.094	10.515	7.409
image18	23.112	20.496	45.481	27.523
image19	18.305	22.301	14.66	15.243
image20	12.493	12.98	18.348	13.679
image21	6.479	6.47	8.403	5.897
image22	8.555	8.072	13.182	8.796
image23	10.691	10.243	11.326	9.88
image24	22.333	21.778	30.421	23.534
Average	9.152	9.11	11.704	8.927

PSNR (dB)				
Image No.	POCS	DSA	IDP	TSDA
image01	39.444	40.147	40.416	40.663
image02	41.429	41.411	41.668	41.84
image03	39.873	39.961	40.057	40.131
image04	41.504	41.488	42.157	41.991
image05	41.784	41.969	41.555	42.466
image06	41.737	41.78	41.439	42.06
image07	42.52	42.708	42.242	43.046
image08	39.216	39.469	38.915	39.214
image09	42.042	41.792	40.602	42.489
image10	41.322	41.057	39.926	41.152
image11	40.576	40.615	39.887	41.008
image12	41.733	41.826	42.778	41.964
image13	38.043	38.566	35.574	37.749
image14	37.389	36.569	36.751	37.415
image15	38.672	39.204	37.062	39.023
image16	35.617	36.04	34.017	35.962
image17	39.312	39.049	37.913	39.433
image18	34.492	35.014	31.552	33.734
image19	35.505	34.648	36.469	36.3
image20	37.164	36.998	35.495	36.77
image21	40.016	40.022	38.887	40.424
image22	38.808	39.061	36.931	38.688
image23	37.841	38.026	37.59	38.183
image24	34.641	34.751	33.299	34.414
Average	39.195	39.257	38.466	39.422

5. Conclusion

This paper proposes a new two stage demosaicing method for CFA images. The proposed method can reduce color errors occurring in the image updating process by adopting high performance interpolation in the first stage. Therefore, the green channel interpolation uses a total amount of the calculation becomes less complicated than existing iterative demosaicing algorithms due to the image updating process without repetition. In order to evaluate the performance algorithm, we have performed various experiments. From the experimental results, our proposed TSDA is better than existing POCS and DSA in terms of visual performance and the comparison results of MSE and PSNR.

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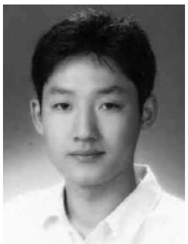

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