International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 2, Issue 4 (July-Aug 2014), PP. 14-18

COLOR FILTER ARRAY DEMOSAICING USING DIRECTIONAL COLOR DIFFERENCE AND GRADIENT METHOD

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***Abstract*— Nowadays digital cameras are equipped with a single sensor (CCD/CMOS), to reduce the size and cost of the camera. The color filter array (CFA) is used to cover the sensor and it consist of three primary colors such as red, green and blue and it samples only one color component at each pixel location. The process of estimating the other two missing color components at each pixel location is known as demosaicing. The proposed algorithm uses the directional color difference and multiscale gradient method for green plane interpolation, this type of interpolation method is used to reduce the artifacts and improve the image quality. The red and blue plane are interpolated using the estimated green plane, the bayer pattern is used for the interpolation technique. The performance of the image is measured using the CPSNR value.**

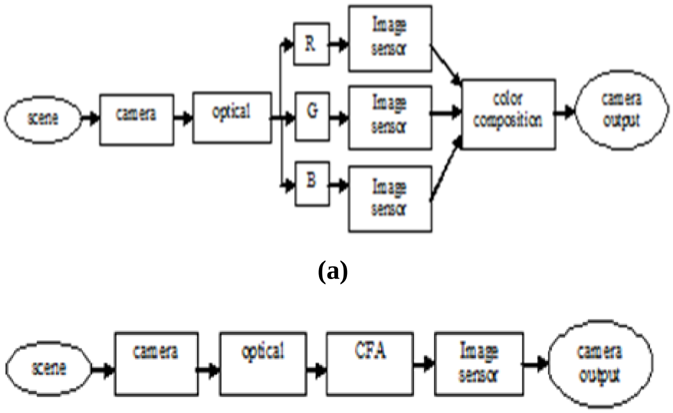
***Key words*— Bayer CFA, Color filter array (CFA), color peak signal-to-noise ratio (CPSNR), charged coupled device (CCD), demosaicing.**

I. INTRODUCTION

Most digital cameras are using single sensor to capture images and it consist of single sensor with color filter array. A full color image is composed of three primary colors such as red, green and blue. The earlier digital still cameras use beam splitter which split the three primary color in three separate sensors and a color filter is placed in front of the three sensors(Fig. 1a). This approach is costly because it required three charge-coupled device(CCD) sensors. In order to reduce the cost and size of the digital camera, nowadays digital still cameras are using single charged coupled device(CCD/CMOS)with color filter array(Fig.1b).

Many CFA pattern are used for demosaicing, some of them are Bayer CFA, Lukac CFA, Plataniotis CFA, Yamanaka CFA and vertical-stripe CFA are shown in Figure. 2. The most popular CFA pattern used for demosaicing is Bayer CFA, it is designed based on the luminance and chrominance level. The CFA samples only one color component at each pixel location and the color arrangement in CFA is alternative color components of red/green and green/blue. In bayer CFA the green component are placed on the quincunx lattice and red and blue component are placed on the rectangular lattice. The green color perceived brightness well because the green color sampled at a higher rate. The green color occupy most of the pixel location in CFA than the other two color because the human visual system(HVS) is more sensitive to green color than red and blue. Bayer CFA consist of 50% of green color & 25% of red and blue color. To get a full color image from the mosaiced image the missing two color component has to be interpolated at each pixel location. The process of interpolating the missing two color component is known as demosaicing.

Demosaicing method is divided into two type, they are iterative method and non-iterative method. The iterative method give higher image quality when compare to non-iterative method. Many interpolation techniques are used for estimating the missing two color component. The bilinear interpolation is the simplest and most efficient method used in earlier demosaicing algorithm, but the major two artifacts are occurred in this type of interpolation techniques.



(a)

(b)

Fig 1. Digital camera system (a) a three sensor device (b) a single sensor device.

The artifacts occurs are blurring and false coloring, due to this reason many new interpolation techniques are implemented, to reduce this kind of artifacts. Later hue based interpolation is implemented is implemented it give better result in avoiding false color, when compare to bilinear interpolation but artifacts are still visible in the border region to overcome this type of interpolation technique edge behavior based interpolation method is estimated.This method give better result in image quality when compare to other interpolation technique.

Another interpolation technique used to reduce artifacts is gradient based method. C. Yen Su [1] uses weighted edge-directed interpolation, this method concentrate more on the horizontal, vertical direction and edges. Lei Zhang [2] uses directional based interpolation technique to reduce artifacts. Daniele Menon [3] uses directional filtering and decision method to estimate green plane and then missing two colors are interpolated using the estimated green plane. In the proposed algorithm color difference and directionally weighted gradient based method is used to estimate the green plane and the estimated green is used to interpolate the missing red and blue plane. This interpolation method give better image quality when compare to other interpolation method discussed above. This paper is organized as follows. Section II describes the proposed methodology for determination of missing red, green and blue pixel values. Section III describes the simulation and results of the proposed algorithm.

II.PROPOSED METHODOLOGY

The proposed system consist of three section A) Block diagram, B) Green channel interpolation, C) Red and Blue channel interpolation. The first step of the algorithm starts with the interpolation of green plane. The color difference [and multiscale gradient method is used to interpolate the green plane. The next step in the algorithm is interpolation of red and blue plane. Then by combining these three plane the fully reconstructed.

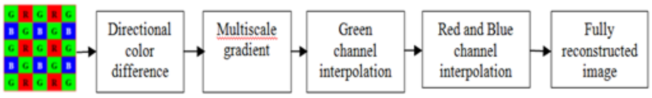


Fig. 2. Block Diagram of proposed system.

color images can be obtained. Fig. 2 shows the block diagram for the proposed algorithm.

A. GREEN CHANNEL INTERPOLATION

Gradient are used for extracting directional data from the input images. Recently several demosaicing algorithms are make use of this method. The Green channel interpolation is based on the directionally weighted gradient method and the directional color difference [5], [14], [19] is used along with the directional data. The bayer pattern consist of red/green rows & columns and blue/green rows & columns. For blue/green rows and columns in the CFA, the directional estimates for the missing blue and green pixel values in horizontal direction are shown in equation (1).

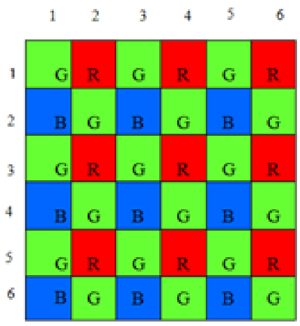


Fig 3. Bayer pattern

$$\tilde{G}^h{}_{2,3} = \frac{G_{2,2}+G_{2,4}}{2} + \frac{2*B_{2,3}-B_{2,1}-B_{2,5}}{4} \qquad (1)$$
$$\tilde{B}^h{}_{2,4} = \frac{B_{2,3}+B_{2,5}}{2} + \frac{2*G_{2,4}-G_{2,2}-G_{2,6}}{4}$$

where h represents the horizontal direction, and represents the missing green and blue pixel values in horizontal direction. For vertical direction the missing green/blue pixel values are estimated from the equation (2).

$$\tilde{G}^v{}_{4,3} = \frac{G_{3,3}+G_{5,3}}{2} + \frac{2*B_{4,3}-B_{2,3}-B_{6,3}}{4} \qquad (2)$$
$$\tilde{B}^v{}_{3,3} = \frac{B_{2,3}+B_{4,3}}{2} + \frac{2*G_{3,3}-G_{1,3}-G_{5,3}}{4}$$

where v represents the vertical direction, and represents the missing green and blue pixel values and (i,j) denotes the pixel location. Likewise the directional estimates for the missing red and green pixel values are estimated. Now a true value for color channel and two directional data are obtained. After estimated the directional data for missing red/green & green/blue rows and columns, then by taking their difference the directional color difference are estimated from the equation (3).

$$\tilde{D}^h{}_{g,b}(2,3) = \tilde{G}^h(2,3) - B(2,3) \text{ , if G is interpolated}$$
$$\tilde{D}^h{}_{g,b}(2,4) = G(2,4) - \tilde{B}^h(2,4) \text{ , if B is interpolated}$$
$$\tilde{D}^v{}_{g,b}(4,3) = \tilde{G}^v(4,3) - B(4,3) \text{ , if G is interpolated}$$
$$\tilde{D}^v{}_{g,b}(3,3) = G(3,3) - \tilde{B}^v(3,3) \text{ , if B is interpolated} \qquad (3)$$

Here $\tilde{D}^h_{g,b}$ and $\tilde{D}^v_{g,b}$ denotes the horizontal and vertical directional color difference estimates between green and blue color. The equation explained above are similar for red/green rows and columns. The horizontal and vertical color difference are combined and calculated as follows in equation (4).

$$gb_{3,3} = G_{3,3} - \frac{B_{2,3}+B_{4,3}}{2}$$
$$gb_{5,3} = G_{5,3} - \frac{B_{6,3}+B_{4,3}}{2}$$
$$gb_{4,2} = G_{4,2} - \frac{B_{4,1}+B_{4,3}}{2}$$
$$gb_{4,4} = G_{4,4} - \frac{B_{4,3}+B_{4,3}}{2} \qquad (4)$$

Where (i,j) are pixel locations and R,G,B denotes the input values. After combining the color difference in both horizontal and vertical direction, the weight is calculated along the four direction, to calculate the weight multiscale gradient based method is used. Normally gradient based method is used to extract the directional data by using this directional data along each direction such as north, south, west and east. The weight is calculated as follows shown in equation (5), for green/blue rows and columns.

$$w_{3,3} = |B_{2,3} - B_{4,3}| + |G_{3,3} - G_{5,3}|$$
$$w_{5,3} = |B_{6,3} - B_{4,3}| + |G_{5,3} - G_{3,3}|$$
$$w_{4,2} = |B_{4,1} - B_{4,3}| + |G_{4,2} - G_{4,4}|$$
$$w_{4,4} = |B_{4,5} - B_{4,3}| + |G_{4,2} - G_{4,4}| \qquad (5)$$

Here W denotes the weight along each direction. The color difference between green/blue and weight along each direction is used to interpolate the missing green pixel vale. The estimation of green plane are calculated as follows in equation (6) & (7)

$$k1 = (gb_{3,3})/(1+w_{3,3})$$
$$k2 = (gb_{5,3})/(1+w_{5,3})$$
$$k3 = (gb_{4,2})/(1+w_{4,2})$$
$$k4 = (gb_{4,4})/(1+w_{4,4})$$
$$kg_{4,3} = (k1+k2+k3+k4)/(1+w_{3,3})+(1+w_{5,3})+(1+w_{4,2}+(1+w_{4,4}) \qquad (6)$$

The estimated green in blue CFA component is calculated as follows in equation (7)

$$\tilde{G}_{4,3} = B_{4,3} + kg_{4,3} \quad (7)$$

Here denotes the estimated green plane and B denotes the input blue CFA component. Similarly calculate the estimated green in red component.

B. RED AND BLUE CHANNEL INTERPOLATION

After interpolating the missing green plane in the red and blue pixel location, next step in the algorithm follows with the interpolation of missing red and blue component. The green plane is interpolated using the directional color difference and gradient based method, the red and blue component is interpolated using constant color difference rule and bilinear interpolation method. The red and blue plane interpolation consist of two sub-steps. The first sub-step involves the process of interpolating the missing blue component at red pixel location and missing red component at blue pixel location. The second sub-step involves the process of interpolating the missing blue and red component at green pixel location.

C. MISSING RED(BLUE)COMPONENT AT BLUE(RED) PIXEL LOCATION

The estimated green channel is consider along the diagonal direction to interpolate the missing red (blue) component at blue (red) pixel location.

$$N1_{4,3} = \left|\tilde{G}_{2,1} - \tilde{G}_{4,3}\right| + \left|\tilde{G}_{3,2} - \tilde{G}_{5,4}\right| + \left|\tilde{G}_{4,3} - \tilde{G}_{6,5}\right|$$

$$N2_{4,3} = \left|\tilde{G}_{2,5} - \tilde{G}_{4,3}\right| + \left|\tilde{G}_{3,4} - \tilde{G}_{5,2}\right| + \left|\tilde{G}_{4,3} - \tilde{G}_{6,1}\right| \quad (8)$$

Here N1 and N2 denotes the normalizer, the red channel is interpolated in blue pixels location are calculated as follows using the equation (8).

$$\tilde{R}_{4,3} = \tilde{G}_{4,3} - \frac{N2*(\tilde{G}_{3,2} - R_{3,2} + \tilde{G}_{5,4} - R_{5,4})}{2*(N1_{4,3} + N2_{4,3})} - \frac{N1*(\tilde{G}_{3,4} - R_{3,4} + \tilde{G}_{5,2} - R_{5,2})}{2*(N1_{4,3} + N2_{4,3)}} \quad (9)$$

Here $\tilde{R}$ and $\tilde{G}$ denotes the estimated green and red component, the equation mentioned above are similar for blue channel estimation at red pixel location.

D. MISSING RED AND BLUE COMPONENT AT GREEN PIXEL LOCATION

The adaptive approach doesn't provide high performance gain in the interpolation of missing red and blue component in green pixel location, so the bilinear interpolation[6],[8],[16] is applied over color difference to get high performance gain. Here the closest two neighboring pixel for the original pixel value are used as shown follows in (10).

$$\tilde{R}_{2,2} = G_{2,2} - \frac{(\tilde{G}_{1,2} - R_{1,2}) + (\tilde{G}_{3,2} - R_{3,2})}{2}$$

$$\tilde{R}_{3,3} = G_{3,3} - \frac{(\tilde{G}_{3,2} - R_{3,2}) + (\tilde{G}_{3,4} - R_{3,4})}{2} \quad (10)$$

Here $\tilde{R}$ denotes the estimated red pixel at green pixel location. Similarly missing blue plane at green pixel is calculated. After completing this step, the green, red and blue plane are combined together to get the fully reconstructed color image. This interpolation technique give better image quality and reduce artifacts.

III.EXPERIMENTAL RESULTS

The proposed work is tested using the 24 Kodak images (shown in fig.4) are used to test performance quality of the proposed demosaicing algorithm. The proposed algorithm is compared with some of the existing algorithm. Three existing algorithm such as bilinear interpolation [4], edge based algorithm [12], and alternate projection [10],[11] are used to compare the performance of the proposed algorithm. The performance is compared with their CPSNR values. The comparison table for the 24 Kodak image with different algorithm is shown in table I. The performance of the proposed algorithm is compared to the existing algorithms.

In demosaicing the quality of the image is measured using Color Mean Squared Error (CMSE), Color Peak Signal-to-Noise Ratio (CPSNR). Color mean square error value is calculated to determine the CPSNR value. It takes the squared difference between the original image and the reconstructed image. CMSE and CPSNR are very simple techniques. CMSE involves first calculating the squared difference between the reference image and demosaiced image at each pixel and for each color channel. These are then summed and divided by three times the area of the image.

Fig. 4 24 Kodak test images [15]

CPSNR is then calculated using CMSE. The equations (11),(12) are shown below.

$$I_{CPSNR} = 10\log_{10}\frac{255^2}{I_{CMSE}} \quad (11)$$

Where I_{CMSE} is a color mean square error value of the image. And its expression is given as

$$I_{CMSE} = \sum_{i,j}\frac{[I_{org}(i,j) - I_{recons}(i,j)]^2}{3*M*N} \quad (12)$$

Where $I_{org}(i,j)$ and $I_{recons}(i,j)$ are the original image and reconstructed image, M and N represents the width and height of the image. The image with higher CPSNR indicates the high quality image. The proposed algorithm reduces the color artifacts and blurring effect in the image.

Image	Bilinear	Edge based	Alternative projection	Proposed Algorithm
1	30.773	31.2458	37.8078	38.8294
2	36.6873	37.0425	39.6512	42.6404
3	37.6775	38.0647	41.63	43.7808
4	37.4213	37.8047	40.16	42.2015
5	31.2157	31.8233	37.5869	39.3311
6	32.1414	32.5964	38.6455	40.1151
7	37.1797	37.6152	41.0256	42.6853
8	28.2879	28.7457	35.0158	38.9985
9	36.4896	36.9292	41.2609	43.2864
10	36.3952	36.8716	40	43.2569
11	33.6645	34.1372	39.006	41.1847
12	36.9695	37.3912	40.5063	43.3886
13	28.6113	29.1087	34.2893	37.9644
14	33.469	33.9611	35.7377	40.1077
15	35.4486	35.8213	39.4739	42.5563
16	35.2366	35.6156	41.2864	41.8311
17	36.681	37.2463	40.6912	42.6004
18	32.562	33.0611	37.9911	40.0843
19	32.7829	33.2797	39.5543	41.0002
20	34.6422	34.9845	37.2988	43.1288
21	33.0627	33.5363	36.9836	41.0325
22	34.9277	35.3907	37.492	41.2275
23	38.3544	38.7374	42.7698	44.8246
24	31.411	31.8746	34.6036	40.4134

Table.1 CPSNR comparisons of proposed algorithm with existing algorithm

Image	Bilinear			Edge based			Alternative Projection			Proposed Algorithm		
	R	**G**	**B**	**R**	**G**	**B**	**R**	**G**	**B**	**R**	**G**	**B**
1	29.741	34.286	29.678	29.741	39.442	29.678	38.881	40.591	39.272	37.45	51.95	37.45
2	35.022	40.797	36.100	35.022	44.854	36.100	36.524	43.533	41.665	40.90	51.95	41.20
3	35.942	41.591	37.252	35.942	45.912	37.252	42.825	45.853	42.113	42.88	51.95	41.68
4	37.106	41.126	35.663	37.106	45.051	35.663	37.928	46.396	44.927	40.53	51.95	40.65
5	30.126	34.082	30.430	30.126	40.240	30.430	37.853	41.500	37.547	37.71	51.95	37.58
6	30.803	35.699	31.355	30.803	40.606	31.355	39.616	41.921	39.609	39.70	51.95	37.47
7	35.514	41.092	36.662	35.514	46.389	36.662	42.159	45.984	40.226	42.14	51.95	40.25
8	27.104	32.181	27.220	27.104	37.959	27.220	34.998	37.820	35.697	37.30	51.95	37.31
9	36.102	40.438	34.717	36.102	45.917	34.717	42.785	45.225	42.298	41.40	51.95	42.07
10	36.272	40.017	34.528	36.272	45.509	34.528	41.980	46.187	43.416	41.47	51.95	41.92
11	32.269	37.035	33.016	32.269	41.880	33.016	39.313	43.338	41.279	40.22	51.95	38.95
12	35.266	41.164	36.404	35.266	36.404	36.404	42.376	46.138	42.872	43.23	51.95	40.77
13	27.650	31.312	27.764	27.650	35.342	27.764	37.443	38.584	36.173	36.37	51.95	36.14
14	32.123	36.675	32.828	32.123	41.524	32.828	34.990	40.838	36.262	39.02	51.95	37.92
15	34.216	39.315	34.439	34.216	43.306	34.439	37.339	43.381	41.055	40.39	51.95	41.62
16	33.815	39.277	34.378	33.815	43.662	34.378	43.143	44.836	42.260	41.98	51.95	38.95
17	36.205	39.248	35.440	36.205	43.949	35.440	43.318	45.433	42.754	40.99	51.95	41.02
18	31.906	35.128	31.478	31.906	38.980	31.478	37.865	41.464	38.428	38.41	51.95	38.41
19	31.592	36.521	31.772	31.592	42.845	31.772	39.476	42.313	40.337	39.53	51.95	39.18
20	33.838	39.032	33.080	33.838	43.287	33.080	41.613	44.279	39.349	41.99	51.97	41.16
21	31.892	36.279	32.221	31.892	40.838	32.221	40.720	42.780	39.923	40.07	51.95	38.80
22	33.866	38.111	33.983	33.866	42.446	33.983	38.562	42.531	38.472	39.45	51.95	39.73
23	36.114	42.556	38.598	36.114	47.324	38.598	41.226	46.550	42.145	43.12	51.95	43.59
24	31.062	34.104	30.016	31.062	37.717	30.016	37.292	40.023	36.291	38.57	51.94	38.94

TABLE.2 PSNR Comparisons of Proposed Algorithm with Existing Algorithm

The table I and II shows that the CPSNR and PSNR value of bilinear interpolation is less when compare to proposed method because it doesn't consider the edges, so the artifacts are produce along the edges. The edge based method used edge based interpolation only for the green channel interpolation, so the CPSNR and PSNR value is less when compare to proposed method. The alternative projection method used transform only for red and blue channel, so the CPSNR and PSNR value is less when compare to proposed method. The proposed method give better image quality when compare to above mentioned algorithm, because directional color difference and gradient based method is used for green channel interpolation and the estimated green plane is used for red and blue plane interpolation.

IV.CONCLUSION

The color artifacts and false colors are some common artifacts in the demosaicing algorithm. The proposed method used directional color difference and gradient based method to reduce such artifacts. This method give better image quality and the computational complexity of this technique is less. CPSNR value shows that the proposed algorithm is able to produce better demosaicing results, when compare to other algorithms. This shows that the proposed method can prove to be useful for image processing problems.

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