Enhanced Directionally Weighted Demosaicing for Digital Cameras

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Abstract

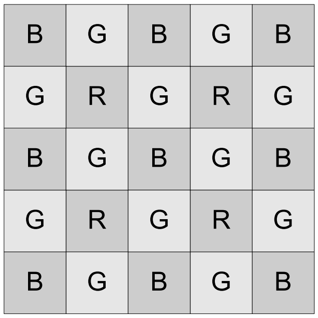
Most digital camera uses the color filter array to reduce the cost and size. When we use the color filter array, however, we need to interpolate the missing pixels. In this paper, we propose an enhanced directionally weighted demosaicing algorithm for the color filtered images of the single-sensor digital camera. The noise can be mixed to the captured image and the min, max, and min-max filters are effective in removing those noises. We use the min, max and min-max filters to reduce the effects of the neighboring noise samples. Compared to the conventional algorithms, the proposed algorithm achieves better visual quality without aliasing artifacts.

1. Introduction

To reduce the size and the cost, the color filter array is used in most commercially available digital camera [1]. When using the color filter array, only a single color component per pixel is obtained. In this reason, we need to interpolate the missing two components per pixel. This process is called as demosaicing or color filter interpolation.

The most commonly used color filter pattern is the Bayer pattern [2] as shown in Fig. 1. The human visual system is more sensitive to the luminance (green) components than to the chrominance (red/blue) components [3]. In this reason, the density of green component is two times more than the one of red/blue component.

The demosaicing algorithms are classified into two groups. The first group interpolates the missing components separately per each color channel. Nearest neighborhood interpolation and bilinear interpolation are included in this group. However the nearest neighborhood interpolation and the bilinear interpolation cause color aliasing effects in edge region. To improve the quality in edge region, the gradient based algorithms have been developed [4]. In the other hand, the other group uses the inter-channel correlation to interpolate missing pixels [5-9]. Since there are high correlations among the color channels in natural image, the algorithms in this group achieve better results than the first group, which does not consider inter-channel correlation.



B	G	B	G	B
G	R	G	R	G
B	G	B	G	B
G	R	G	R	G
B	G	B	G	B

Fig. 1. Bayer pattern.

2. Proposed Algorithm

2.1. Step 1: Interpolate missing green values

In most case, the missing pixels are interpolated by neighboring pixels. In this paper, we consider twelve directions to increase the edge sensitivity. The directions are illustrated in Figure 2. Usually the missing green value on B33 is interpolated by G23, G32, G34, and G43. Additionally the proposed algorithm uses G12, G14, G21, G25, G41, G45, G52, and G54 to detect the edge sensitively. The directions are numbered from 1 to 12 as Fig. 2 for the convenience of expression. The difference, D_n, between the samples in direction n is defined by

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Table 1. Offsets of nearby samples in step 1, 3

n	v_n	h_n	n	v_n	h_n
1	0	-1	7	+2	+1
2	+1	0	8	+1	+2
3	-1	0	9	-1	+2
4	0	+1	10	-2	+1
5	+1	-2	11	-2	-1
6	+2	-1	12	-1	-2

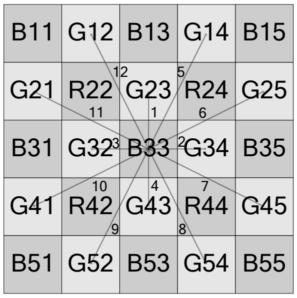


Fig. 2. Directions of interpolation in step 1, 3.

$$D_n(i,j) = \left|P(i+v_n, j+h_n) - P(i-v_n, j-h_n)\right| + \left|P(i+2v_n, j+2h_n) - P(i,j)\right| \tag{1}$$

where, $P(i, j)$ denotes the sample on position (i, j). The offsets, v_n and h_n, of neighboring pixels used in interpolation are listed in Table 1.

Since the red and blue channels are highly correlated with the green channel, color differences between red/blue and green are effective to interpolate the missing values

To reconstruct the missing value on (i, j), we interpolate the missing value with weighted sum of the color differences. Weight for the direction n, $w_{org,n}(i, j)$, is defined by

$$w_{org,n}(i,j) = \frac{1}{1 + D_n(i,j)}. \tag{2}$$

To reduce the effect of the noise, we first adjust the weight in direction which has the minimum weight (min-filter), maximum weight (max-filter) or both of minimum and maximum weight (min-max filter).

$$w_n = \begin{cases} 0, & for\ n = \min\arg(w_{org}) \text{ ... min(-max) filter} \\ 0, & for\ n = \max\arg(w_{org}) \text{ ... (min-)max filter} \\ w_{org,n}, & otherwise \end{cases}. \tag{3}$$

$$w_{sum} = \sum_{n=1}^{12} w_n . \tag{4}$$

The missing green value on the blue sample is interpolated by adding blue value $B(i, j)$ and the weighted sum of the color differences between the green value G and the blue value B.

$$G(i,j) = B(i,j) + \sum_{n=1}^{12} \frac{w_n(i,j)}{w_{sum}(i,j)} \cdot K_n^B(i,j) \tag{5}$$

where, $K_n^B(i, j) = G(i+v_n, j+h_n) - B(i+v_n, j+h_n)$.

The color difference $K_n^B(i, j)$ is calculated by subtracting the blue value from the green value in direction n. The blue value on green sample is required, however there isn't the blue value, the average of nearby blue samples is used instead.

Interpolating the missing green value, $G(i, j)$, on the red sample is almost same as above.

$$G(i,j) = R(i,j) + \sum_{n=1}^{12} \frac{w_n(i,j)}{w_{sum}(i,j)} \cdot K_n^R(i,j) \tag{6}$$

where, $K_n^R(i, j) = G(i+v_n, j+h_n) - R(i+v_n, j+h_n)$.

$K_n^R(i, j)$ is the color difference between red and green value in direction n. Similarly the red value on the green sample is not existed, we use the average of nearby red samples.

2.2. Step 2: Interpolate missing red/blue values on blue/red samples

As shown in Fig. 3, there are no nearby samples of desired color, except four diagonal directions, so we only consider these four directions. The offsets used in this step are listed in Table 2. The difference, D'_n, between the samples in direction n is defined by

$$D'_n(i,j) = \left|P(i+v'_n, j+h'_n) - P(i-v'_n, j-h'_n)\right| + \left|P(i+2v'_n, j+2h'_n) - P(i,j)\right|. \tag{7}$$

Table 2. Offsets of nearby samples in step 2

n	v'_n	h'_n	n	v'_n	h'_n
1	+1	-1	3	-1	+1
2	+1	+1	4	-1	-1

Fig. 3. Directions of interpolation in step 2.

The weight for the direction n is calculated by

$$w'_{org,n}(i,j) = \frac{1}{1 + D'_n(i,j)}. \tag{8}$$

After applying the min-max filter, weight for each direction is adjusted as follows:

$$w'_n = \begin{cases} 0, & for\ n = \min\arg(w'_{org}) \text{ ... min(-max) filter} \\ 0, & for\ n = \max\arg(w'_{org}) \text{ ... (min-)max filter} \\ w'_{org,n}, & otherwise \end{cases}. \tag{9}$$

$$w'_{sum} = \sum_{n=1}^{4} w'_n. \tag{10}$$

Similar to the step 1, missing blue value on the red sample is calculated by adding green value and the weighted sum of the difference between the green and blue values.

$$B(i,j) = G(i,j) - \sum_{n=1}^{4} \frac{w'_n(i,j)}{w'_{sum}(i,j)} \cdot K_n^B(i,j) \tag{11}$$

where, K_n^B is obtained from (5).

The interpolation of missing blue values on the red sample is similar to (11).

2.3. Step 3: Interpolate missing red/blue values on green samples

The missing blue value on the green sample is obtained as in (12)

$$B(i,j) = G(i,j) - \sum_{n=1}^{12} \frac{w_n(i,j)}{w_{sum}(i,j)} \cdot K_n^B(i,j) \tag{12}$$

where $w_n(i, j)$ is obtained from (3), $w_{sum}(i, j)$ is obtained from (4) and K_n^B is obtained from (5). The interpolation of the missing red values on the green samples are same as (12).

3. Experimental Results

We compared the proposed demosaicing algorithm with some conventional algorithms for various test images. For the image simulation, we used the images of the motor, the statue, the necklace, the lighthouse, the airplane, and the building from the Kodak image database. These images are shown in Fig. 4. Table 3 shows the PSNR comparison for the bilinear interpolation, GB (Gradient Based) algorithm [4], C2D2 (Color Correlations and Directional Derivatives) [6], DWCI (Directionally Weighted Color Interpolation) [7], and the proposed algorithms. In most cases, the proposed algorithm with max filter achieves the highest PSNR than the other demosaicing algorithms.

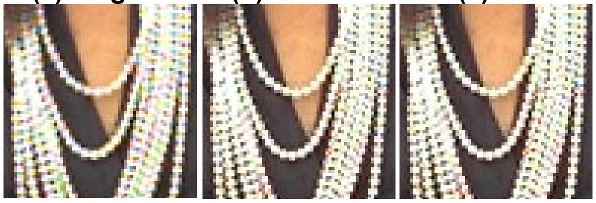
Fig. 5. (a) show the magnified details of the original necklace image. Fig. 5. (b to i) are first downsampled to Bayer pattern and then reconstructed to full color image. The results of the proposed algorithm with min-max filter and max filter show less color aliasing artifacts than the conventional algorithms. Fig. 6. (a) is the magnified one of the original building image. Fig. 6. (b to i) are also downsampled to Bayer pattern and then interpolated to full color images. It can be seen that the proposed algorithm reduce color aliasing artifacts around complicated edge region.


(a) Motor (b) Statue (c) Necklace


(d) Lighthouse (e) Airplane (f) Building

Fig. 4. Set of testing images.


(a) Original (b) Bilinear (c) GB


(d) C2D2 (e) DWCI: linear (f) DWCI: stochastic


(g) Proposed: min-filter (h) Proposed: min-max filter (i) Proposed: max filter

Fig. 5. Results of simulation (the necklace).

Table 3. PSNR(dB) comparison

		Bilinear	GB [4]	C2D2 [6]	DWCI: linear [7]	DWCI: stochastic [7]	Proposed: min filter	Proposed: min-max filter	Proposed: max filter
Motor	All	27.382	31.918	35.081	35.418	35.489	35.674	35.607	**35.808**
	R	26.685	31.935	35.104	35.585	35.665	35.894	35.569	**35.935**
	G	29.140	31.760	34.965	36.885	36.956	36.688	37.593	**38.018**
	B	26.741	32.063	35.176	34.197	34.262	**34.679**	34.277	34.263
Airplane	All	32.221	36.654	38.967	38.671	38.739	**39.060**	38.484	38.510
	R	31.714	36.798	38.938	39.393	39.478	**39.899**	39.076	39.204
	G	33.929	36.893	39.450	40.949	41.009	40.996	40.880	**41.049**
	B	31.425	36.294	38.518	36.737	36.799	**37.199**	36.577	36.496
Necklace	All	28.492	32.130	34.759	35.770	35.814	35.906	35.837	**36.050**
	R	28.237	32.432	35.263	35.575	35.626	35.740	35.589	**35.828**
	G	30.011	32.374	35.067	37.781	37.830	37.900	38.177	**38.458**
	B	27.576	31.630	34.047	34.549	34.585	34.669	34.509	**34.672**
Building	All	23.067	25.834	28.221	29.913	29.956	29.664	29.912	**30.130**
	R	22.001	25.478	25.725	28.501	28.544	28.679	28.803	**28.967**
	G	26.914	26.339	28.889	32.788	**32.815**	30.980	31.581	31.815
	B	21.896	25.728	28.129	29.500	29.549	29.635	29.790	**30.066**
Lighthouse	All	28.471	35.459	37.148	37.955	**38.030**	38.025	37.195	37.495
	R	27.851	35.407	36.950	37.131	37.213	**37.442**	36.588	36.943
	G	30.099	35.918	38.136	41.205	**41.256**	40.182	39.317	39.582
	B	27.830	35.093	36.515	36.757	36.834	**37.064**	36.274	36.540
Statue	All	32.763	36.401	39.192	40.099	40.139	40.168	40.180	**40.383**
	R	32.432	36.763	39.605	40.279	40.327	40.420	40.378	**40.545**
	G	34.665	36.463	37.706	42.184	42.220	42.025	42.417	**42.779**
	B	31.708	36.011	32.063	38.571	38.608	38.694	38.576	**38.739**


(a) Original


(b) Bilinear


(c) Gradient Based [4]


(d) C2D2 [6]


(e) DWCI: linear [7]


(f) DWCI: stochastic [7]


(g) Proposed: min-filter


(h) Proposed: min-max filter


(i) Proposed: max-filter

Fig. 6. Results of simulation (the building).

4. Conclusion

In this paper we propose the enhanced directionally weighted demosaicing algorithm for Bayer color filter array. In this algorithm, we use both directional derivative and color correlation concepts and proposed algorithms show less color aliasing artifacts with min, max, and min-max filters.

5. References

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