Effective False Color Suppression of Demosaicing Using Direction Inversion and Bidirectional Signal Correlation

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ABSTRACT

This paper presents an effective algorithm to suppress the false colors of demosaicing. Firstly, the Hamilton's edge detector is used to estimate the interpolated directions of missing green samples. Secondly, a direction map is built. A direction different from others within an $M \times N$ neighborhood is modified by using the proposed direction-inversion rule. The interpolated direction of each missing green sample is finally determined by comparing its weighted bidirectional signal correlation. As compared to the latest algorithm for suppressing false colors, the proposed one not only eliminates more false colors but also produces a higher average peak-signal to noise ratio.

***Index Terms*—**Interpolation, Image reconstruction

I. INTRODUCTION

Most of the prevalent digital still cameras (DSCs) use only one color sensor, covered with a color filter array (CFA), to reduce their cost [1]. However, this will lead to that two colors at each pixel are missed. The process of recovering the missing colors is called as demosaicing or color interpolation.

The most common CFA pattern is the Bayer pattern [2] as shown in Fig. 1. For this pattern, many demosaicing algorithms have been proposed to estimate the missing colors. Among them, edge directed methods generally produce more satisfying reconstructed images because they handle well at the edge regions or sharp transition regions. However, they might incur color artifacts (or false color) if edge detectors fail. For example, the two cases illustrated in Fig. 2 will cause Hamilton's edge detector [3] failure. In Fig. 2(a), the missing green sample at center is a high value but it is estimated by a low value because a small variation of illumination on its two vertical neighbors results in a wrong edge direction detected (in vertical direction). Similarly, the actual value of the center of Fig. 2(b) is low but will be estimated as a high value due to a wrong edge direction detected (in horizontal direction).

To solve this problem, a cost-effective color filter array

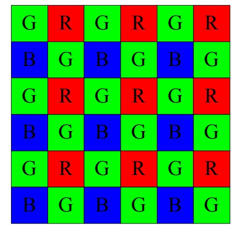
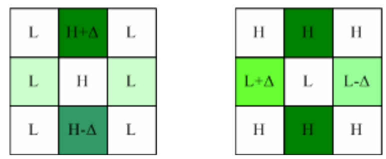


Fig. 1. Bayer CFA pattern



(a) (b)

Fig. 2. Two examples of detection failure by Hamilton's edge detector. (a) The estimated edge direction of center is vertical but it is horizontal actually. (b) The estimated edge direction of center is horizontal but it is vertical actually.

demosaicing (CECFA) was proposed recently [7]. The main idea of CECFA is to use the directional information of adjacent pixels to determine the direction of the current pixel. Since CECFA only takes unidirectional signal correlation into account (left for horizontal detector and top for vertical detector), it might produce wrong interpolation direction especially at color transition regions or at the sample with erroneous detected directions on its left or top missing neighbors. To cope with these situations, we propose an effective algorithm which not only uses the property of bidirectional signal correlation but also uses a direction-inversion rule to correct many erroneous directions.

This paper is organized as follows. Section II briefly introduces CECFA [7] interpolation to G channel. Section III details the proposed method. Experimental results of applying our method to successive approximation (SA) [5] and highly effective iterative demosaicing (HEID) [6] are shown in Section IV. Finally, we conclude this paper in Section V.

II. PREVIOUS METHOD

The idea behind CECFA is to slightly modify

Hamilton's edge-sensitive interpolation to G channel. Specifically, CECFA replaces Hamilton's horizontal (DH) and vertical (DV) classifiers by two new classifiers (DH' and DV'), which are defined as

$$DH' = DH - w \cdot d_{j,i-2} \quad (1)$$

$$DV' = DV + w \cdot d_{j-2,i} \quad (2)$$

where w is a weight, $d_{j,i-2}$ and $d_{j-2,i}$ represent the directional information of its left and top missing green samples respectively, and $d_{j,i}$ is given by

$$d_{j,i} = \begin{cases} 1 & \text{if } DH < DV \\ 0 & \text{if } DH = DV \\ -1 & \text{if } DH > DV \end{cases} . \quad (3)$$

Here, $d_{j,i}$=1 means that the edge direction of pixel (j,i) is treated as horizontal; $d_{j,i}$=0 denotes no obvious edge; and $d_{j,i}$=-1 represents a vertical edge. Since the direction of adjacent pixels along horizontal or vertical edge is almost the same, the directional information of adjacent pixels can be used to determine the direction of the current pixel.

In (1), if $d_{j,i-2}$=1, the value of horizontal classifier is reduced by an amount of w, which increases the probability of choosing the horizontal predictor (GH) to interpolate the current pixel. On the other hand, if $d_{j,i-2}$=-1, the value of horizontal classifier increased, resulting in that the current pixel is less likely interpolated by GH. As for $d_{j,i-2}$=0, the value of DH' is the same as DH, leading to no influence on the choice of predictor of current pixel. A similar effect of $d_{j-2,i}$ in (2) will affect the decision of vertical predictor GV.

III. PROPOSED METHOD

Although CECFA can eliminate most visible color artifacts, it might fail at color transition samples or at the samples with erroneous directions detected on its left or top neighbors.

To solve these problems and keep the computational complexity as low as possible, we propose the ideas of using bidirectional signal correlation and direction inversion.

A. Bidirectional signal correlation

The proposed bidirectional signal-correlation method is a modified version of CECFA. For the decision of horizontal/vertical edge, it not only uses the directional information of left/top green sample, but also uses the directional information of right/bottom green sample into account. The proposed horizontal (DH'') and vertical (DV'') classifiers are given by

$$DH'' = DH - w \cdot [d_{j,i-2} + d_{j,i+2}] \quad (4)$$

$$DV'' = DV + w \cdot [d_{j-2,i} + d_{j+2,i}] . \quad (5)$$

In (4), if both $d_{j,i-2}$ and $d_{j,i+2}$ are 1 (horizontal edge), the value of DH'' is largely reduced from DH, resulting in a high probability to choose the horizontal predictor (GH) in the process of choosing a predictor. If one of them is 1 and the other is 0 (no obvious edge), the value of DH'' is slightly reduced by an amount of w. At this case, it seems that the edge direction of current pixel begins to change. If one of them is 1 and the other is -1 (vertical edge) or both of them are 0, DH'' is equal to DH, meaning that the directions of adjacent pixels do not affect the decision of the direction of current pixel. Similarly, the directional information of top sample ($d_{j-2,i}$) and bottom sample ($d_{j+2,i}$) is used to help the decision of the direction of current pixel. For example, in (5), if both $d_{j-2,i}$ and $d_{j+2,i}$ are -1 (vertical edge), the value of DV'' is largely reduced from DV, leading to a high probability to choose the vertical predictor (GV). Compared to CECFA, the proposed classifier requires only one more addition but it will suppress more color artifacts as we can see in Section IV. An example illustrating this improvement is shown in Fig. 4.

B. Direction inversion

To improve the accuracy of edge detection, one way is to use more complicated predictors. However, it might increase the computational complexity significantly. In order not to increase the computation significantly, we propose a direction-inversion rule. The main idea of direction inversion is to change the direction of a pixel if its direction is different from others in a small homogeneous region R. This likes using a filter to remove the *salt-and-pepper* noise. The direction-inversion rule is defined as following:

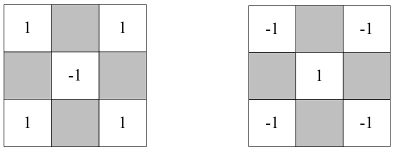
$$\text{If } d_{n,m} = -d_{j,i} \text{ for all } (n,m) \in R \text{ and } (n,m) \neq (j,i),$$
$$\text{then } d_{j,i} = -d_{j,i} . \quad (6)$$

Fig. 3 shows two cases of direction inversion in a 3x3 region. In Fig. 3(a), the direction of center will be changed to be 1 because all the directions of its neighbors are 1. Similarly, the direction of center in Fig. 3(b) will be changed to be -1.

C. Complete algorithm

The complete algorithm of integrating the proposed two ideas into Hamilton's edge-sensitive interpolation to G channel is as below.

1) Form DH and DV classifiers by Hamilton's classifiers.
2) Build a direction map by using (3).
3) Apply the direction-inversion rule to the direction map.
4) Replace both DH and DV by DH'' and DV'' in the process of choosing a predictor.



(a) (b)

Fig. 3. Examples of direction inversion. (a) the direction of center will be changed to be 1. (b) the direction of center will be changed to be -1.

D. Discussion

It is difficult to determine the direction of a green sample in a regular transition region like the fence of "Lighthouse". If the estimated direction is wrong, it will cause that a horizontal interpolation appears at a vertical edge or a vertical interpolation occurs at a horizontal edge. These will cause serious color artifacts. Fig. 4 illustrates one of such examples in the image of "Lighthouse". In Fig. 4(c), it is obvious that color artifacts exist even though using an iterative interpolation. In Fig. 4(d), some color artifacts are eliminated. However, many color artifacts still exist because some directions determined by *DH* and *DV* are wrong, which worsens the direction decision of using *DH*' and *DV*'. From the Fig. 4(e), we can see that the proposed direction inversion effectively suppress color artifacts in the fence regions. In Fig. 4(f), as we expected, it results in the best reconstructed image.

IV. SIMULATION RESULTS

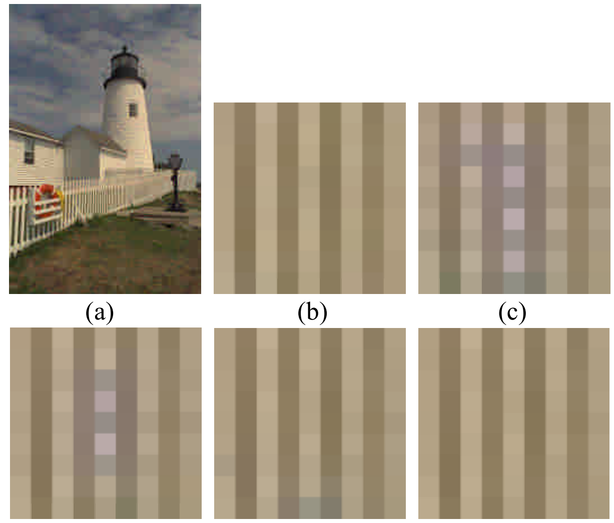
The tested images (shown in Fig. 5) are 24 Kodak photographic images of 512x768 pixels which are the same as those used in [7]. The mean squared error (MSE) and peak-signal to noise ratio (PSNR) are used to measure the performance of different algorithms. They are defined as following.

$$MSE = \frac{1}{H \times W} \sum_{j=1}^{H} \sum_{i=1}^{W} (f_{j,i} - \hat{f}_{j,i})^2 \quad (7)$$

$$PSNR = 10 \log_{10} \frac{255^2}{MSE}, \quad (8)$$

where H and W represent the height and width of an image, $f_{j,i}$ is a practical value, and $\hat{f}_{j,i}$ is the estimated value.

In [7], the authors mentioned that CECFA produces desirable and robust performance when w=15. Though our best weight is not 15, we can still use this value for comparison.



(a) (b) (c)

(d) (e) (f)

Fig. 4. Examples to illustrate the color artifacts.(a) the original image of Lighthouse; (b) a zoomed part of fence region in Lighthouse image; (c) the demosaiced image by SA [5]; (d) the demosaiced image of applying CECFA [7] into SA; (e) the demosaiced image of using the proposed direction inversion to SA; (f) the demosaiced image of applying both the proposed direction inversion and bidirectional signal correlation into SA.

Fig. 5. Images used in the experiment.

Table I shows the comparison of applying different methods to SA and HEID respectively. Compared to the original SA, the scheme of adding CECFA decreases the MSE from 0.05 to 0.17 and increases the PSNR up to 0.09dB while the scheme of adding the proposed method decreases the MSE from 0.13 to 0.31 and increases the PSNR from 0.16dB to 0.18dB. Thus, the proposed method has a better performance than CECFA. As compared to the original HEID, the scheme of adding CECFA decreases the MSE from 0.05 to 0.16 and increases the PSNR from 0.07dB to 0.1dB while the scheme of adding the proposed method can decrease the MSE from 0.16 to 0.29 and increase the PSNR from 0.16dB to 0.24dB. Furthermore, if the best weight w=51 is chosen, the proposed scheme can decrease the MSE up to 0.3 and increase the PSNR up to 0.27dB.

To show the visual effect of our method, we magnify and compare the reconstructed images of different algorithms. Fig. 6 exhibits the comparison in a portion of the fence of image 8, which is a challenging region for many demosaicing algorithms. As shown in this figure, the proposed method suppresses more color artifacts than CECFA. Fig. 7 illustrates average increment of PSNR from w=1 to 60. The proposed method increases PSNR gradually and approaches to a constant when w is larger than 30, while CECFA produces some exceptions especially at w=7. Investigating the results, we find that for image 7 the PSNR is largely decreased if w is not well designed. This probably arises from that image 7 is full of the sea and the neighboring pixels of the pixels in the sea have a low correlation in edge direction.

TABLE I
AVERAGED PERFORMANCE COMPARISON RELATED TO THE COLOR IMAGES SHOWN IN FIG. 5

MATHOD	CHANNEL	MSE	PSNR
SA [5]	R	11.59	38.31
	G	5.26	41.70
	B	10.95	38.46
Apply CECFA [7] to SA	R	11.42	38.40
	G	5.21	41.77
	B	10.81	38.54
Apply the proposed algorithm to SA	R	11.28	38.49
	G	5.13	41.86
	B	10.67	38.63
HEID [6]	R	11.30	38.62
	G	4.65	42.27
	B	10.30	38.79
Apply CECFA [7] to HEID	R	11.18	38.69
	G	4.60	42.34
	B	10.14	38.89
Apply the proposed algorithm to HEID	R	11.04	38.78
	G	4.49	42.51
	B	10.01	38.98

V. CONCLUSION

In this paper, we established an algorithm to suppress the color artifacts of demosaicing. The proposed algorithm uses bidirectional signal correlation to elevate the accuracy of interpolated directions and uses a direction-inversion rule to handle the noise caused by illumination variation. Simulation results verify the effectiveness of the proposed algorithm subjectively and objectively.

VI. REFERENCES

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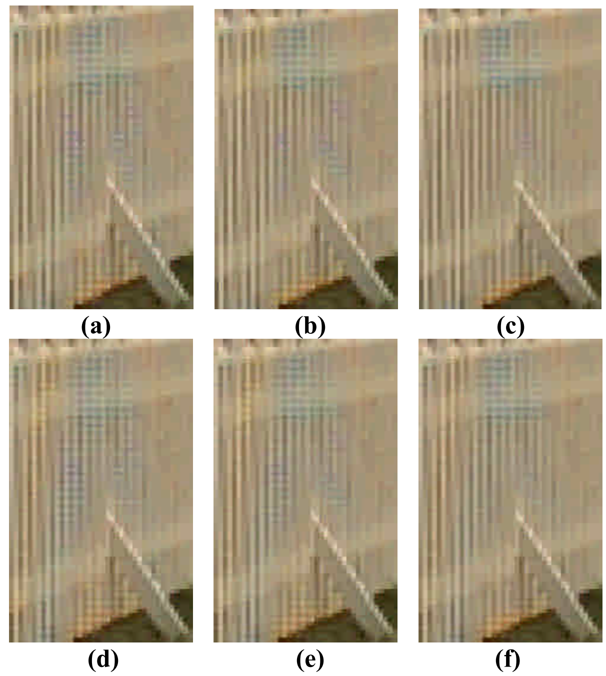

Fig. 6. Comparison of color artifacts in a portion of image 8. Reconstructed by (a) original SA [5], (b) applying CECFA [7] to SA, (c) applying the proposed algorithm to SA, (d) original HEID [6], (e) applying CECFA to HEID, (f) applying the proposed algorithm to HEID.

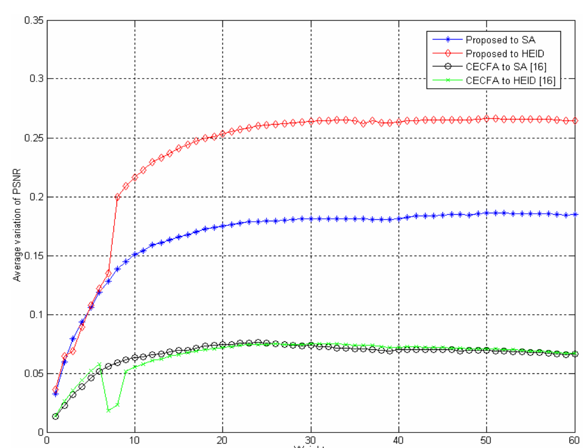

Fig. 7 Average increment of PSNR from w=1 to 60 when applying different methods to SA and HEID.