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Edge-Sensing Demosaicing based on Modified Edge Indicator

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Abstract:

In this paper, we propose a demosaicing algorithm which interpolates the missing pixels on the estimated edge direction with modified edge indicator. We use gradients to estimate the edge direction which considers cross-channel correlation in addition to the within-channel correlation. After the edge direction is estimated, we interpolate the missing color values more precisely in aid of weighted color difference values. The experimental results show that the proposed method outperforms the conventional methods, both on objective and subjective criteria.

Keyword : Color interpolation, Bayer pattern, Directional interpolation, Cross-channel correlation.

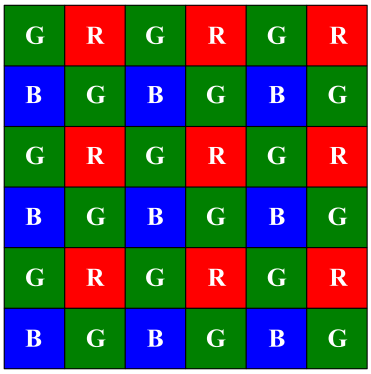


Figure 1. Bayer pattern.

1. Introduction

In typical digital camera, the color images are acquired by using a single-chip CCD or CMOS image sensor array, where each pixel obtains one of the color components, such as red, green, or blue, in aid of special color filter array (CFA). The most widely used CFA is proposed by Bayer [1]. In Bayer CFA pattern shown in Fig. 1, red and blue color filters are arranged with rectangular grid while green color filters are arranged with quincunx grid. Due to the sampling by CFA, there is missing color values in each pixel. The process to restore the color values is called *demosaicing* or *color interpolation*. A number of techniques are proposed to find the missing color information from CFA [2]. Bilinear, cubic, or B-spline interpolation schemes are used in simplest demosaicing methods. In these methods, the color channels are interpolated separately without considering correlation between channels, and therefore, fine details of an image are blurred and visible artifacts are produced. They are shown as zippers on object boundaries or Moiré effect appeared by being lost the high-frequency components from CFA sampling in the resulting images.

To reduce the artifacts in the high-frequency region, Kimmel proposed a demosaicing scheme based on the smooth hue transition assumption to use the correlation between channels [3]. In the color model, the ratio between luminance and chrominance at the same position is assumed to be constant in the neighborhood. Park and Kang improved the color interpolation method with accurate weighting function [4]. Similar to the ratio model, difference between channels are assumed to be constant within the neighborhood in cross-channel color difference model [5]. In these methods, the artifacts are effectively reduced by using the correlation between channels. Based on the difference model, the missing values in each color channel is interpolated on the edge direction which has minimum error [6]. In [7], modified interpolation method of difference domain is presented for reduced computational cost maintaining the demosaicing performance.

However, there still remains artifacts on high frequencies with sharp edges. In another kind of method, Adams and Hamilton proposed a heuristic interpolation method that missing color values are interpolated in particular direction [8]. They sense edge direction as horizontal or vertical direction by detecting gradient of pixels in a target channel. In [9], Wu and Zhang made horizontally and vertically interpolated intensities and chose one of them by soft-decision criterion, which is based on Fisher's linear discriminant.

In this paper, we proposed a direction oriented color interpolation algorithm considering correlation between color channels with modified edge indicator. We consider the edge direction as horizontal or vertical direction corresponding to conventional edge sensing methods and estimate the direction by using both of gradients between neighboring pixels in a channel and in a different channel. As the gradient on a channel is based on the within-channel correlation, that on a different channel is directly based on the cross-channel correlation. This additional gradient adopts the similarity of high-frequencies between color channels and improves the method to find more edges in complicated region precisely. In interpolation process, weights are used to interpolate more accurate edge direction and it is performed on the color difference domain. The proposed edge-sensing algorithm interpolates edges with less color artifacts and without blurring especially on high-frequency regions.

The organization of the paper is as follows. In Section 2, the basic assumptions and the details of the proposed method is presented. The pixels in each color channel are directionally interpolated in the difference domain. Section 3 presents experimental results of the proposed method. Finally, the paper is closed with the conclusion in Section 4.

2. Proposed Demosaicing Method

2.1 Color Difference Model

In the proposed demosaicing method, the correlation between channels are utilized based on the color difference model. In color difference model, red or blue values and green values are assumed to be correlated to within an offset term, such as,

$$\begin{aligned} G &= R + \Delta_R. \\ G &= B + \Delta_B. \end{aligned} \tag{1}$$

Because the red, green and blue color planes of an image tend to be correlated, assumptions on this image model becomes valid. By using this image model it is assumed that the red and blue values are correlated to the green values over the extent of the interpolation pixel neighborhood [5]. Based on this assumption, the color difference domain K_R and K_B is defined as

$$\begin{aligned} K^R(i,j) &= G(i,j) - R(i,j), \\ K^B(i,j) &= G(i,j) - B(i,j). \end{aligned} \tag{2}$$

In case of the Bayer pattern, however, there are two missing color values on each pixel location. For example, the green channel sampling location, there is no red or blue value and the color difference model cannot be adopted directly. In [5], the bilinear interpolated values of red or blue are used as follows

$$\begin{aligned} K^R(i,j) &= G(i,j) - (R(i-1,j) + R(i+1,j))/2, \\ K^B(i,j) &= G(i,j) - (B(i-1,j) + B(i+1,j))/2. \end{aligned} \tag{3}$$

In the following interpolation procedure, the missing color values are interpolated on the color difference domain as depicted above.

2.2 Proposed Edge Sensing Demosaicing Method on G channel

The sampling frequency of green channel is twice as high as that of red or blue channel. Moreover, finding missing green channel can assist the subsequent red and blue plane interpolation, as the green channel can be thought as intensity of an image. From these reasons, interpolation of missing green channel is performed before than that of red and blue channel. The entire demosaicing process at each channel is composed of two steps. First, the direction of interpolation at each pixel location is determined using within-channel and cross-channel correlations. After the interpolation direction at a pixel is found out, the missing pixel values are filled with weighted mean value.

In conventional edge-sensing methods, the criterion for edge direction estimation is most important since the quality of resulting image is directly determined by the determination step. If the direction were mis-estimated, the estimated direction is opposite to original edge direction. Consequently, errors from these misalignment is highly visible and reducing these artifacts are challenging issue for edge-sensing methods. To improve the accuracy of edge direction determination, we propose a novel estimation criterion, such as,

$$\begin{aligned} \Delta H &= \Delta \underline{G}_H + \Delta \underline{A}_H + \Delta \underline{GA}_H, \\ \Delta V &= \Delta \underline{G}_V + \Delta \underline{A}_V + \Delta \underline{GA}_V, \end{aligned} \tag{4}$$

where ΔH and ΔV represents gradient in horizontal and vertical direction, respectively. In each of the gradient, they are composed of three different kinds of gradient values, $\Delta \underline{G}_H$, $\Delta \underline{A}_H$, and $\Delta \underline{GA}_H$ in case of ΔH, which are defined as,

$$\begin{aligned} \Delta \underline{G}_H &= \sum_{k,l} (|G(i+k,j+l) - G(i+k,j+l+2)| \\ &\quad -|G(i+k,j+l) - G(i+k,j+l-2)|), \\ \Delta \underline{A}_H &= \sum_{k,l} (|A(i+k,j+l) - A(i+k,j+l+2)| \\ &\quad -|A(i+k,j+l) - A(i+k,j+l-2)|), \\ \Delta \underline{GA}_H &= \sum_{k,l} (|G(i+k,j+l) - A(i+k,j+l+1)| \\ &\quad -|G(i+k,j+l) - A(i+k,j+l-1)|), \end{aligned} \tag{5}$$

for horizontal direction. They are gradient between pixels in green channel, chrominance channel, such as red or blue, and gradient between pixels in different channels. The concept of first and second one is used in conventional edge-sensing method which are based on the within-channel correlation and cross-channel correlation. $\Delta \underline{G}_H$ represents edge is located where the lower value of gradient within a green channel, which is to be interpolated. The similar consideration is represented in $\Delta \underline{A}_H$ where A is a channel that contains the pixel under consideration. In the proposed method, we adopt second order gradient to improve the edge indicating performance of these criterion. In addition to the second order gradient on the green and chrominance channel, the gradient of pixels between each channel values in the neighborhood are calculated in $\Delta \underline{GA}_H$. They works as a fine edge region detector such as repeatedly appeared edges. From the under-sampling process, high frequencies are distorted and the detection of repeated fine edge region is difficult. The last gradient plays a main roll for detect these region by using the correlation between pixels in different channels. After the direction of a pixel is determined, the missing value is interpolated similar to the edge sensing methods, such as,

$$\bar{G}(i,j) = \begin{cases} A(i,j) + \sum_{(l)} wK^A_{i,j+l} & \text{if } \Delta H < \Delta V, \\ A(i,j) + \sum_{(k)} wK^A_{i+k,j} & \text{else if } \Delta H > \Delta V, \\ A(i,j) + \sum_{(k,l)} wK^A_{i+k,j+l} & \text{otherwise,} \end{cases} \tag{6}$$

where, $wK^A_{i+k,j+l}$ represents weighted value on a color difference domain, such as

$$wK^A_{i+k,j+l} = e(i+k, j+l) \times K^A(i+k, j+l). \quad (7)$$

and

$$\sum_{(k,l)} e(i+k, j+l) = 1. \quad (8)$$

Note that, the resultant green values are calculated with weight functions which is not used in the conventional edge-sensing methods.

2.3 Proposed Edge Sensing Demosaicing Method on R, B channel

In the interpolation of the red and blue channels, the same criterion for determining the edge direction is used. However, it is composed of two seperate steps, since the sampling rate of red and blue channels are half of the green channel. At first step, the red or blue pixel values at the blue or red pixel sampling location is obtained, respectively. Since there is four sampled pixels at each corner of neighborhood square, it is obtained as

$$\bar{A}(i,j) = \sum_{(k,l)} \bar{G}(i,j) - w\bar{K}^A_{i+k,j+l}, \quad (9)$$

where, $\bar{G}(i,j)$ represents the interpolated green pixel and $w\bar{K}^A_{i,j}$ represents the color difference value using interpolated values. After the missing pixels on different chrominance values are calculated, the pixels on the green value sampled location is considered using previously interpolated pixels. In this case, the gradient defined in Eq. (5) is changed since the fully interpolated green channel is obtained from the previous step. For example, the gradients used in horizontal directional edge-sensing criterion is changed as

$$\begin{aligned}
\Delta \underline{G}_H &= \sum_{k,l} (|G(i+k, j+l) - G(i+k, j+l+1)| \\
&\quad - |G(i+k, j+l) - G(i+k, j+l-1)|), \\
\Delta \underline{A}_H &= \sum_{k,l} (|A(i+k, j+l) - A(i+k, j+l+2)| \\
&\quad - |A(i+k, j+l) - A(i+k, j+l-2)|), \\
\Delta \underline{GA}_H &= \sum_{k,l} (|G(i+k, j+l) - A(i+k, j+l+1)| \\
&\quad - |G(i+k, j+l) - A(i+k, j+l-1)|).
\end{aligned} \quad (10)$$

The vertical directional edge-sensing criterion is calculated in the same way.

$$\bar{A}(i,j) = \begin{cases} G(i,j) - \sum_{(l)} w\bar{K}^A_{i,j+l} & \text{if } \Delta H < \Delta V, \\ G(i,j) - \sum_{(k)} w\bar{K}^A_{i+k,j} & \text{else if } \Delta H > \Delta V, \\ G(i,j) - \sum_{(k,l)} w\bar{K}^A_{i+k,j+l} & \text{otherwise,} \end{cases} \quad (11)$$

PSNR (dB)		Pei	Hamilton	Wu	Proposed
bike	R	34.95	34.74	34.75	**37.11**
	G	36.83	35.93	36.35	**38.82**
	B	34.74	34.38	34.39	**36.34**
house	R	29.93	31.69	31.45	**34.95**
	G	33.09	33.48	34.07	**36.80**
	B	29.88	31.69	31.49	**35.03**
sails	R	38.64	39.41	39.66	**41.30**
	G	41.37	41.37	42.06	**43.51**
	B	39.33	40.04	40.34	**42.06**
ribbon	R	36.20	35.83	35.90	**36.77**
	G	41.10	39.43	40.03	**41.95**
	B	39.12	37.77	38.02	**40.26**
statue	R	39.12	38.52	38.34	**40.59**
	G	40.35	39.30	39.66	**41.46**
	B	38.62	37.79	37.93	**39.93**
lighthouse	R	34.72	33.47	33.31	**35.61**
	G	36.50	34.80	35.06	**36.95**
	B	34.85	33.40	33.37	**35.76**

Table 1. The PSNR comparison of conventional methods and the proposed method. Each row of a image represent red, green, and blue channel, seperately

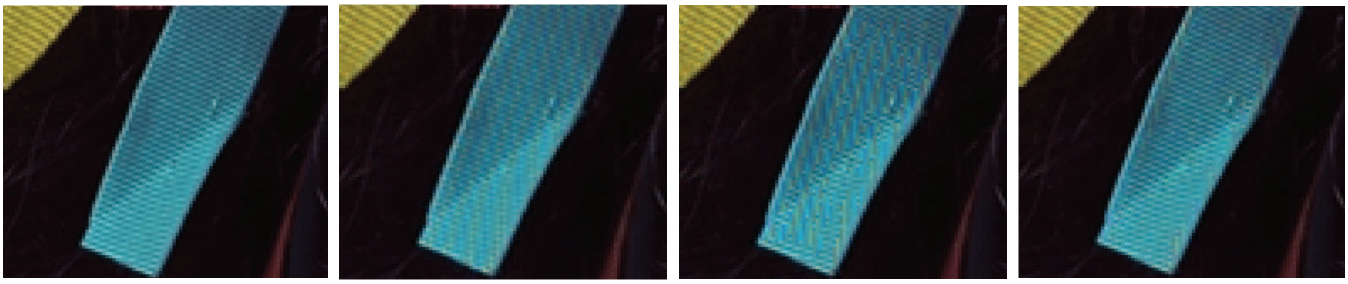
3. Experimental Results

We present a simulation result to demonstrate the performance of the proposed method, which is compared with conventional algorithms, such as Hamilton's method which used the edge-sensing technique, Pei's algorithm [5] that is based on the color difference model and Wu's method [9] that selects edge direction between horizontal and vertical direction. The tested color images are 'bike','house', 'sails', 'ribbon' , 'statue', and 'lighthouse' which are obtained from film captured test images by Kodak. The performance of each methods is depicted in Table 1 in terms of PSNR values. Among the conventional methods, Pei's or Wu's method show high in most of the images. The proposed method shows highest PSNR value in all simulated images. The numerical values in the table shows that the proposed method using modified edge-sensing technique outperforms the conventional methods.

To show the subjective comparison, we depict the resulting images in Fig. 2 and Fig. 3 . As shown in Fig. 2 (a), line edges and repeated edge pattern are shown for comparing the performance in the complicate edge region. In the result from Pei's method shown in (b), the resulting image from conventional method based on the color difference domain is depicted, where the zipper effects are appeared on every object boundaries and Moire effects are shown. In the result from Wu's method in (c), the zippers are removed and the edges are sharpened by using edge-sensing technique of the conventional method. However, the Moire in the repeated edges are still remained. In the results of proposed method shown in the last figure, the novel edge sensing criterion shows improved performance especially on the window frame without Moire effect. By exploiting local edge information with the modified edge sensing indicator, the proposed method reduces visible

(a) (b) (c) (d)

Figure 2. Resultant image (a) original image (b) Pei's method (c) Wu's method (d) proposed method



(a) (b) (c) (d)

Figure 3. Resultant image (a) original image (b) Pei's method (c) Wu's method (d) proposed method

artifacts on the edge region and restores clear edges without blurring. The similar results are shown in Fig. 3. Pei's algorithm still fails to interpolate the missing values without zipper effect. In (c), the interpolation error from the miss guided direction is bigger than that of averaging the neighbors on K_R and K_B domain in case of false interpolation. The result of proposed algorithm has less color artifact and more continuous line as shown in Fig. 3 (d).

4. Conclusion

In this paper, we have proposed a demosacing algorithm which estimates edge direction with modified edge sensing function. The gradient between channels are used in addition to the within a channel which utilize the correlation between channels. The consideration of the cross-channel correlation in the gradient improves the accuracy in the resulting images especially on the complicated edge regions. In the interpolation process, color difference domain and weight functions are used to find the missing color values. In the resulting images and numerical comparisons, the proposed method outperforms the conventional methods by using accurate edge sensing method that adopt the correlation between channels.

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