Region adaptive demosaicing

Chang Won Kim, Joonyoung Chang and Moon Gi Kang
Institute of TMS Information Technology, Yonsei University
134, Shinchon-Dong, Seodaemoon-Ku, Seoul 120-749, Korea
E-mail: freezer98@yonsei.ac.kr

Abstract: The problem of recovering full-color images from color-sampled observation is considered in this paper. In order to avoid artifacts in high frequency regions and improve the performance, region is classified into flat, edge and pattern region, and edge indicator function is used. The horizontal and vertical direction of edge is decided using local statistics based on the concepts of spectral-spatial correlation. As a postprocessing, the modified filtering on color difference domain is adopted to improve the quality of the image. Experimental results illustrate the benefits of the proposed method. When compared to the conventional methods, the proposed method outperforms them on quantitative and qualitative criteria.

1. Introduction

Single-chip image sensor which is most widely used in digital still camera uses color filter arrays to obtain different color information at each pixel location. The Bayer pattern [1] shown in Fig. 1 is the most widely used CFA pattern.

In order to obtain full color image from Bayer CFA CFA demosaicing process is required. Several CFA demosaicing algorithms have been proposed in recent papers. Based on the assumption of smooth hue transition in the neighborhood, Pei and Tam introduced the color difference domain, based on the color difference model [2]. Interpolation on the color difference domain can consider correlation with less hardware complexity. Since human visual systems are sensitive to the edge in an image, many demosaicing methods try to avoid interpolating across edges [3][4]. Lu et al. computed the gradients in the 7X7 support region and used color adjusted values for green channel interpolation [3]. Although artifacts have been reduced by utilizing these color interpolation algorithms mentioned above, undesirable color artifacts still remain along the edges and in the high frequency region of the image. To suppress color artifacts, several color correction methods have been attempted [3]-[5]. Recent demosaicing approach uses horizontally and vertically interpolated images to determine the direction of edges accurately [7]-[9].

In this paper, based on the concepts of spectral-spatial correlation(SSC) [9] the three types of region is classified firstly in the four sub block respectively then the direction of edge is decided using local statistics. These process makes the decision of the edge direction more accurately. The advantages of proposed region adaptive demosaicing scheme will be shown clearly through the demonstration of algorithms and experimental results. This paper is organized as follows. The concepts of spectral-spatial correlation(SSC) is introduced in Section 2. And the detailed explanation of the proposed algorithm and its theoretical improvements are presented. Experimental results and comparisons with other algorithms are given in section 3. We conclude in Section 4.

2. Region adaptive demosaicing

The concept of spectral and spatial correlation is that the color difference between green and red or blue is constant over neighboring pixel and toward an edge direction, the rate of change of neighboring pixel values is constant [9].

Based on the concept following equation is derived,

\[ D^{GR} = G6 - R5 = (G6 - G5) + (G5 - R5) = dG + K_R. \] (1)

where \( K_R = G - R \) is defined in the color difference model [2]. This shows that the difference between neighboring pixel is same as the summation of spectral and spatial correlations.

2.1 Region classification

For more accurate decision of edge direction, the region is classified into flat, edge and pattern region in bayer CFA.

![Figure 1. The Bayer pattern](image1)

![Figure 2. Spectral and spatial correlation](image2)
Also bayer CFA is divided into four sub region which is north, south, east and west sub block to decide the types of region.

For each sub region in Fig. 4-5, $D_{\text{edge}}$ and $D_{\text{flat}}$ is calculated as

$$D_{\text{edge}} = |A_{-2} - A| + |A_{+2} - A| + |G_{-1} - G_{+1}|,$$

$$D_{\text{flat}} = |G - G_{\pm 1}|.$$  

Comparing $D_{\text{edge}}$ and $D_{\text{flat}}$ with predefined threshold, region is classified into flat, edge and pattern region.

2.2 Demosaicing

In a Bayer CFA, the green plane is sampled at a rate twice as high as the red and blue planes. Thus, the aliasing in the green plane tend to be less than the one in the red and blue planes. Green plane possesses the most spatial information of the image to be interpolated and has great influence on the visual quality of the image. For these reasons, green plane interpolation should be preceded.

Referring to Fig. 1, in order to estimate the missing $G_5$ values at $R_5$ pixel location, $D^{GR}$ values around it should be calculated. Using $D^{GR}$ values and the results of region classification $G_5$ value is obtained by

$$G_5 = R_5 + K^R,$$

where $K^R$ is a weight sum of surrounding $D^{GR}$ value. From Eq. 1, $D^{GR}$ is equal to $K_R$ when $dG$ is zero. It means that weight sum of $D^{GR}$ calculated in the homogeneous region is same as $K_R$. Therefore $K^R$ can be expressed as

$$K^R = \frac{\sum_{k \in h} e(k)D^{GR}_k}{\sum_{k \in h} e(k)},$$

where $k$ is north, south, east and west sub region and $h$ is a support region. The results of region classification and the variance of $D^{GR}$ at each sub region determines the weight function $e(k)$. $e(k)$ is 0 when sub region is classified as edge region, otherwise $e(k)$ has a value which is inverse proportion of the variance of $D^{GR}$. $D^{GR}$ is calculated using a weight sum of neighboring $D^{GR}$ value in the each sub region. Subsequently, the estimated $D^{GR}$ values are replaced by $D^{GR}$ so that they will be involved in the calculating the local statistics of the next pixels to decide direction of edge at the next pixel location. The interpolation of $G$ values at $B$ pixel locations are performed in a similar way as $R$ pixel location.

2.3 Red and blue plane interpolation

Although the red and the blue planes are more sparsely sampled than the green planes, they are easily interpolated by using the fully interpolated green plane and $K^R$ and $K^B$ domains. Similar to the green plane interpolation the missing $R$ value at the $B$ location is estimated adaptively by

$$R_{i,j} = G_{i,j} + \frac{\sum_{k,l \in h} w^R_{i-k,j-l}K^R_{i-k,j-l}}{\sum_{k,l \in h} w^R_{i-k,j-l}}.$$  

where $(k, l) = \{(-1, -1), (-1, +1), (+1, -1), (+1, +1)\}$. In this case, $K_R$ is calculated directly using fully interpolated $G$ channel values. $w$ is the same as the one in the green plane except for the different pixel location. The interpolation of $R$ values at the $G$ location and the interpolation of $B$ values are performed in a similar way as interpolation of $R$ value at the $B$ location.

2.4 Color correction algorithm

In order to suppress visible artifacts residing in the interpolated image, median filtering is performed in the color difference domain as a color correction process [3]. Based on Tan’s
method, color correction updates the R,G,B values adaptively [5][6].

\[ G_{i,j}^R = R_{i,j} + \hat{K}_{i,j}^R, \quad G_{i,j}^B = B_{i,j} + \hat{K}_{i,j}^B, \]

(7)

where \( \hat{K}_{i,j}^R = \text{median}\{K_{i,j}^R(i,j) \in h\} \), \( \hat{K}_{i,j}^B = \text{median}\{K_{i,j}^B(i,j) \in h\} \), and \( h \) denotes the support of the 5x5 local windows. The updated \( G \) value is determined by the weighted sum of two updated \( G^R \) and \( G^B \) values of each color difference domain and original \( G \) value. Subsequently, \( R \) and \( B \) values are updated using the updated \( G \) value. This process is expressed as

\[ \hat{G}_{i,j} = \left\{ (1-a)G_{i,j}^R + aG_{i,j}^B \right\}, \]

(8)

\[ \hat{R}_{i,j} = \left\{ \hat{G}_{i,j} - \hat{K}_{i,j}^R \right\}, \]

(9)

and

\[ \hat{B}_{i,j} = \left\{ \hat{G}_{i,j} - \hat{K}_{i,j}^B \right\}, \]

(10)

where \( \hat{G}_{i,j} \) is the initially interpolated value of the green channel, \( \hat{G}_{i,j} \) is an updated value of the green channel, and \( a \) is a weight. The weight \( a \) is expressed as

\[ a = \frac{\sigma_{\hat{K}^B}}{\sigma_{\hat{K}^R} + \sigma_{\hat{K}^B}}, \quad 0 < a < 1 \]

(11)

Subsequently, the color values of the central pixel are replaced by \( \hat{R}, \hat{G} \) and \( \hat{B} \) so that they will be involved in filtering the updating pixels.

3. Experimental Results

In the experiments, the performance of the proposed algorithm was tested with 25 Kodak test images with an RGB Bayer pattern. The average of PSNR of R,G and B channel and the normalized color difference (NCD) [10], which is an objective measure of the perceptual error between two color images, were used in order to measure the performance of the proposed algorithm quantitatively. The PSNR was defined in decibels as

\[ \text{PSNR} = 10 \log_{10} \frac{255^2 \cdot N}{\| \hat{x} - x \|^2}, \]

where \( N \) is the total number of pixels in the image, \( x \) is the original image, and \( \hat{x} \) is the interpolated image. The NCD is computed in the \( L^*a^*b^* \) color space by using the following equation:

\[ \text{NCD} = \frac{1}{M} \sum_{i=1}^{M} \sum_{j=1}^{N} \left\| \Delta E_{\text{Lab}} \right\|, \]

where \( \Delta E_{\text{Lab}} \) is the perceptual color error between two color vectors and is defined as the Euclidean distance between them, and is given by

\[ \Delta E_{\text{Lab}} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}, \]

where \( \Delta L^*, \Delta a^*, \) and \( \Delta b^* \) are the differences in the \( L^*, a^*, \) and \( b^* \) components. The magnitude of the pixel vector in the \( L^*a^*b^* \) of the original image is \( E_{\text{Lab}}^* \) and is given by

\[ E_{\text{Lab}}^* = [(L^*)^2 + (a^*)^2 + (b^*)^2]^{1/2}. \]

For a visual comparison Kodak 1 and 19 image is shown in Fig. 6 and Fig. 7. From the Fig. 6, the proposed method shows less zipper and moire artifacts in the window compared with conventional method. From the Fig. 7, the proposed method shows less visual artifacts in the fence region compared with conventional method. For a visual comparison Kodak 1 and 19 image is shown in Table 1 and Table 2. The proposed algorithm improves the PSNR from about 0.3 dB to about 4 dB and the NCD from 0.02 to 1.5 compared with the conventional methods. Experimental results show that the advantages of the proposed algorithm in both the quantitative and qualitative criteria.

4. Conclusion

A region adaptive demosaicing algorithm was proposed in this paper. To facilitate this, color demosaicing was performed based on the concept of spectral and spatial correlation. And horizontally and vertically interpolated values are optimally chose to estimate the values more accurately. We
introduced the weight function which reflected cross-channel correlation and considered the directions of the edges to suppress artifacts in the edge region. In the color correction step, the adaptive filter in the color difference domain has been adopted for suppressing color artifacts which still remained in the color interpolated image. The updated values were determined by adaptively combining two median values. Experiments were carried out with various images. Simulation results of the proposed algorithm indicated that the proposed region adaptive demosaicing outperformed the conventional algorithms in both the quantitative and the qualitative criteria.

Acknowledgment
This research was supported by the MIC(Ministry of Information and Communication), Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute for Information Technology Advancement)” (IITA-2008-(C1090-0801-0012))

References
[2] Soo-Chang Pei, Io-Kuong Tam, “Effective color interpolation in CCD color filter arrays using signal correla-