Subsampled Channel Difference for Color Image Enhancement

Seungjong Kim
Department of Computer Science & Information Systems,
Hanyang Women’s University, Korea
jkim@hywoman.ac.kr

Abstract. In this paper, a new demosaicking method is proposed which has three stages: (1) green channel restoration, (2) red/blue channel restoration, and (3) three channels refinement. The proposed method uses channel difference information and parameter applied weighted average approaches. Simulation results informs that the presented method outperforms conventional benchmark one.

Keywords: color image, image interpolation, color difference, upsampling quality assessment.

1 Introduction

The color image is generally composed of multi-color channels, and at least three color sensors are required to show color image. When a color image is acquired using a CFA, it is needed to populate the R, G, and B intensities so that there is a reconstruct of all 3 color intensities for each sensor position [1-3]. Once the population is accomplished, each pixel has 3 color intensities and can be manipulated by various image processing methods. To reduce the cost, currently available digital cameras uses color filter array (CFA) to obtain a color image. Therefore, each pixel only captures one color, and this process is mosaicking, and the opposite process is demosaicking [4-5]. The opposite process stands for reconstructing missing two colors information. One of mostly successfully CFAs is Bayer pattern CFA [6]. In Bayer pattern CFA, each pair has four pixels, two are from green channel and the other two are from red/blue channel, respectively.

There have been several demosaicking methods with diverse degree of complexity and accuracy. One of simplest methods is bilinear interpolations which are considered to be the straightforward approach where the missing color information is reconstructed in a single color component independently. Thus, the high frequency component cannot be well restored. One of the most well-known direction based method is adaptive color plane interpolation algorithm. By considering inter-channel correlation, some advanced methods were presented to try to preserve edge details and provide better color demosaicking result. For instance, the ECI method is proposed to achieve full color image by restoring the color channels between green
and red/blue components. Based on effective color interpolation approach, other
demosaicking methods were proposed. The primary-consistent soft-decision approach
removes color components artifacts by undertaking the same demosaicking direction
for each color component of a pixel. These all methods were based on adaptive color
plane interpolation algorithm with more accurate edge direction computing [7-8].

This paper proposes a new color interpolation approach which has three steps. In
the first step, the green channel is reconstructed based on color channel difference. In
the second step, red or blue channel interpolation is accomplished using pre-computed
green channel information. Finally, refinement process is applied to remove outlier
pixels.

2 Proposed Method

The proposed method restored the green channel first. Then other color components
(red and blue) are restored using already restored green channel. As the green channel
has more usable information, employing restored green channel for red/blue
restoration is helpful. For example, it is assumed that the center pixel is located at (i, j)
and the center pixel color component is red. There are four edge directions, 0°(H),
90°(V), 45°(UR), and 135°(UL) gradients at (i, j) locations. Then, \( H_{i,j}, V_{i,j}, UR_{i,j}, \) and
UL\(_{ij}\) are computed as follows:

\[
\begin{align*}
H_{i,j} & = [G_{i,j+1} - G_{i,j}] + \alpha [R_{i,j-2} - 2R_{i,j} + R_{i,j+2}], \\
V_{i,j} & = [G_{i+1,j} - G_{i-1,j}] + \alpha [R_{i,j-2} - 2R_{i,j} + R_{i,j+2}], \\
UR_{i,j} & = [G_{i,j+1} - G_{i,j-1}] + \frac{1}{2} + \alpha [R_{i-2,j+2} - 2R_{i,j} + R_{i+2,j-2}], \\
UL_{i,j} & = [G_{i,j+1} - G_{i,j-1}] + \frac{1}{2} + \alpha [R_{i-2,j+2} - 2R_{i,j} + R_{i+2,j-2}].
\end{align*}
\]

Figure 1 shows four cases of edge directions. If \( \alpha \) is smaller (or bigger) than 1, then
green pixels have more (or less) influence to determine direction. It is assumed that
the missing green (MG) components are obtained by following equations:

\[
\begin{align*}
MG_{i,j}^{Ht} & = (G_{i,j+1} + G_{i,j-1})/2 - \beta (R_{i,j-2} - 2R_{i,j} + R_{i,j+2})/4, \\
MG_{i,j}^{Vt} & = (G_{i+1,j} + G_{i-1,j})/2 - \beta (R_{i,j-2} - 2R_{i,j} + R_{i,j+2})/4, \\
MG_{i,j}^{URt} & = (G_{i,j+1} + G_{i,j-1} + G_{i+1,j} + G_{i-1,j})/4 - \beta (R_{i,j-2} - 2R_{i,j} + R_{i,j+2})/4, \\
MG_{i,j}^{ULt} & = (G_{i,j+1} + G_{i,j-1} + G_{i+1,j} + G_{i-1,j})/4 - \beta (R_{i,j-2} - 2R_{i,j} + R_{i,j+2})/4.
\end{align*}
\]

After the green channel is restored, remained red and blue channels are restored. As
the interpolated green channel is reliable, the green channel information is adopted
for investigating red and blue channels. The unknown red/blue channels are
components at green CFA sampling positions are populated. Figure 2 shows two
examples that a green pixel is positioned at the center of 5×5 block. The only
difference is that the red pixels are horizontally located in Fig. 2(a) while the blue pixels are horizontally located in Fig. 2(b).

For the blue channel interpolation at red location, information located in the diagonal direction could be good estimates for interpolation. The red and blue information are populated by Equations (3) and (4), respectively. In this step, $\lambda_1$ and $\lambda_2$ are weight parameters for left and right, or upper and lower directions.

When red/blue components are positioned in green channel, there are two scenarios. To obtain red and blue channels in Fig. 2(a), the bi-cubic interpolation method is recommended. The red channel is horizontally interpolated while blue channel is vertically interpolated:

$$R_{i,j} = G_{i,j} + \lambda_1 (R_{i-1,j} - G_{i-1,j}) + \lambda_2 (R_{i,j+1} - G_{i,j+1}).$$

$$B_{i,j} = G_{i,j} + \lambda_1 (B_{i,j-1} - G_{i,j-1}) + \lambda_2 (B_{i+1,j} - G_{i+1,j}).$$

\hspace{1cm} (3)

\hspace{1cm} (4)

Fig. 2. Two 5x5 blocks of Bayer CFA: (a) red pixels are horizontally located, (b) blue pixels are horizontally located.
For the case of Fig. 2(b), the red channel is interpolated vertically and the blue channel is interpolated horizontally as follows:

\[
B_{i,j} = G_{i,j} + \frac{1}{4} \left( B_{i,j-1} - G_{i,j-1} + 3 \left( B_{i,j+1} - G_{i,j+1} \right) + 3 \left( B_{i,j+3} - G_{i,j+3} \right) - \left( B_{i,j+5} - G_{i,j+5} \right) \right)
\] (6)

\[
R_{i,j} = G_{i,j} + \frac{1}{4} \left( R_{i,j-1} - G_{i,j-1} + 3 \left( R_{i,j+1} - G_{i,j+1} \right) + 3 \left( R_{i,j+3} - G_{i,j+3} \right) - \left( R_{i,j+5} - G_{i,j+5} \right) \right)
\] (7)

\[
B_{i,j} = G_{i,j} + \frac{1}{4} \left( B_{i+1,j} - G_{i+1,j} + 3 \left( B_{i+3,j} - G_{i+3,j} \right) + 3 \left( B_{i+5,j} - G_{i+5,j} \right) - \left( B_{i+7,j} - G_{i+7,j} \right) \right)
\] (8)

3 Simulation Results

The proposed approach is tested on 20 LC images (#51-70). All test images are initially executed by Bayer CFA pattern and then interpolated back to three color components using the proposed color interpolation method. The reconstructed images are compared to the original image with several objective metrics such as color peak signal to noise ratio (CPSNR), color mean squared error (CMSE), and S-CIELAB. It is noted that pixels within eleven pixel distance from the border area are not examined in the experiments. The first two metrics are CPSNR and CMSE. The CMSE is calculated as Equation (9).

\[
CMSE = \frac{1}{3HW} \sum_{i=(R,G,B)} \sum_{x=1}^{H} \sum_{y=1}^{V} \left[ ori(x,y,i) - rec(x,y,i) \right]^2,
\] (9)

where \( ori \) and \( rec \) stand for the original image and the demosaicked images. Parameters \( x, y, \) and \( i \) are horizontal position, vertical position, and color channel number, respectively. \( H \) is the image height and \( W \) is the width of test image. For LC dataset, \( H \) and \( W \) are 540 and 720, respectively. Once CMSE is computed, then CPSNR can be computed as,

\[
CPSNR = 20 \log_{10} \left( \frac{255}{\sqrt{CMSE}} \right).
\] (10)

The predetermined parameters \( \alpha=1.2, \beta=0.8, \lambda_1=0.9 \) and \( \lambda_2=0.9 \) are used in this paper.

Figure 3 shows simulation results comparison on LC #69 image. The proposed approach well restores image similar to the original one. This can be found from Fig. 3(e). On the other hand, the benchmark method shows undesirable color errors as shown in Fig. 3(d).
Fig. 3. Subjective performance comparison on LC #69 image: (a) original image, (b) bilinear interpolation, (c) proposed method, (d) difference between (a) and (b), and (e) difference between (a) and (c).

Fig. 4. Objective performance comparison in terms of MSE: (a) red channel MSE, (b) green channel MSE, (c) blue channel MSE, and (d) CMSE.
4 Conclusion

Due to the cost reason, current digital cameras adopt color filter array instead of beam splitters of full-color RGB camera. The proposed method restores color image from a given CFA image. The proposed method has three steps: (1) green channel interpolation, (2) red/blue channel interpolation, and (3) all channels refinement. As green component has more information than that of red or blue components, it is suggested to restore green channel first before red or blue channel. Simulation results inform that the proposed approach gives reliable results in terms of visual and objective performance.

Acknowledgments. This research was supported by 2016-2 Hanyang Women’s University Research Fund.

References