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Effective Demosaicking for Bayer Color Filter Arrays with Directional Filtering and Weighting Technique

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Abstract - *Digital cameras usually use a single sensor covered with a color filter array which samples only one color at the location of each pixel. Restoring a full-color image by the demosaicking technique is a key task in the digital imaging pipeline. This paper proposes a novel demosaicking approach based on the existing directional filtering and weighting techniques. The contributions of this paper are two-fold. Firstly, we analyze the advantages and limitations of the existing directional filtering and weighting techniques, and improve the two existing techniques in order to suppress the common demosaicking artifacts. Secondly, we give a new estimated scheme for the reconstruction of the color components. Experimental results show that the proposed method outperforms the recent six state-of-the-art demosaicking methods in terms of both subjective and objective measures.*

Key Words: **Demosaicking, Directional Filtering, Weighting technique, MATLAB, Color filters, RGB.**

1. INTRODUCTION

Digital cameras have become ubiquitous during the last decade. In a digital camera, a color image is often produced using red (R), green (G), and blue (B) three color samples at each pixel location. In order to reduce cost and size, a lot of cameras use a single sensor covered with a color filter array (CFA). The CFA allows only one color to be measured at each pixel. The missing other two color values at each pixel must be estimated. This estimation process is known as demosaicking. To produce a color image, there should be at least three color samples at each pixel location. One approach is to use beam-splitters along the optical path to project the image onto three separate sensors as illustrated in Figure 1.

Using a color filter in front of each sensor, three full-channel. color images are obtained. This is a costly approach as it requires three charge-coupled device (CCD) sensors and moreover these sensors have to be aligned precisely (a nontrivial challenge to mechanical design).

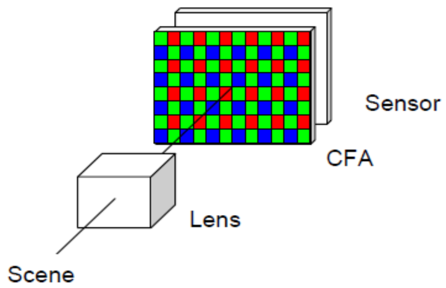

Fig.1: Illustration of optical paths for single-chip digital cameras

A more cost-effective solution is to put a color filter array (CFA) in front of the sensor to capture one color component at a pixel and then interpolate the missing two color components.22 Because of the mosaic pattern of the CFA, this interpolation process has been widely known as "demosaicing".

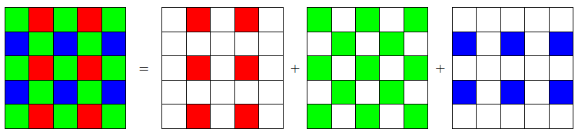

Fig.2: Bayer pattern used in single-chip digital cameras

Among many CFA patterns, the most commonly used is the Bayer. The Bayer pattern measures the green image on a quincunx grid (half of the image resolution) and the red and blue images on rectangular grids (quarter of the image resolution). The green channel is measured at a higher sampling rate than the other two because the peak sensitivity of the human visual system (HVS) lies in the medium wavelengths, corresponding to the green portion of the spectrum.

Recently, many CFA patterns have been found to exist. The most common pattern is the Bayer CFA. Here we only consider the Bayer pattern illustrated in Figure in which the G values are sampled on a quincunx grid, while the R and B values are sampled on rectangular grids.

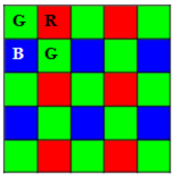

Fig.3: Bayer color filter array

2. PROPOSED METHODOLOGY

The main objective of this study is to explore how to efficiently improve and combine the existing directional filtering and weighting schemes in order to alleviate the common demosaicking artifacts. Because DFPD almost removes the grid errors in the G plane, our interpolation in the G plane is based on DFPD, and our main improvement to DFPD consists in the interpolations of the missing G values on the weak edges by the weighted average of two orthogonal directional G values; analogously, because EECI can commendably suppress false colors, our interpolations in the R and B planes have a similar weighting scheme to EECI, and our main improvement to EECI consists in calculating weights on the color difference planes.

The proposed algorithm includes two steps: initial step and refinement step. In the initial step, the initial estimates of the R, G and B planes are computed, while in the refinement step, the G plane can be further refined using the initial R and B planes and vice versa. The principle of the proposed algorithm will be further illustrated in the following.

3. RGB INTERPOLATION

3.1interpolation of the Green Plane

We have seen in Section II that the edge-directed DFPD almost eliminates the zipper artifacts in the example of Fig. 2. However, in the textured regions, the detected direction of an edge tends to be incorrect and the inordinate false colors are caused (Fig. 3). Based on the observations, we consider improving the interpolation of the G plane in DFPD. For an explicit horizontal or vertical edge, we estimate the missing G values using DFPD. Otherwise the G values are estimated using the weighted average of two orthogonal directional G values, where the choice of weights is dependent on the strength of the horizontal and vertical directional edges across the missing pixel. The interpolation of the G plane comprises two steps: directional interpolation step and decision step.

1) Directional interpolation step: This step interpolates the missing G values using the ACPI interpolator in horizontal and vertical directions respectively. Estimating the missing G value at an R pixel will be considered [Fig. 4]. The interpolation at a B pixel can be carried out similarly. Let's find G5 at R5.

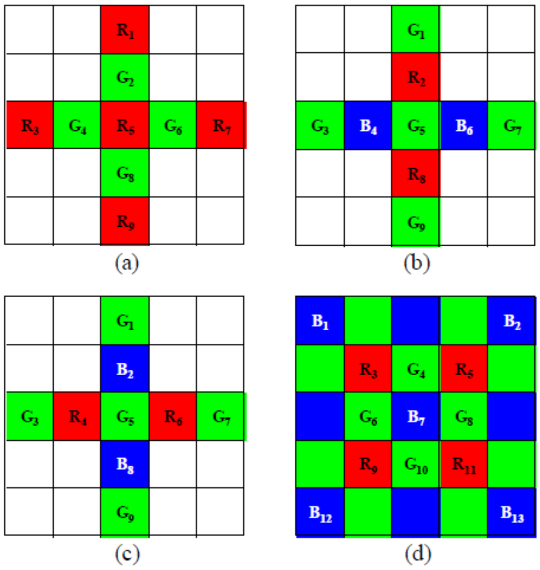

Fig.4: Reference CFA samples

$$\begin{cases} G_5^H = (G_4 + G_6)/2 + (R_5 - R_3 + R_5 - R_7)/4 \\ G_5^V = (G_2 + G_8)/2 + (R_5 - R_1 + R_5 - R_9)/4 \end{cases}$$

2) Decision step: Once the G plane has been interpolated along both horizontal and vertical directions, two G images will have been produced. It is required to select a better direction from the two directions for every pixel. Therefore, two colour difference images are computed as:

$$C_H(i,j) = \begin{cases} R_{i,j} - G_{i,j}^H, & \text{if } (i,j) \text{ is a red location} \\ B_{i,j} - G_{i,j}^H, & \text{if } (i,j) \text{ is a blue location} \end{cases}$$

$$C_V(i,j) = \begin{cases} R_{i,j} - G_{i,j}^V, & \text{if } (i,j) \text{ is a red location} \\ B_{i,j} - G_{i,j}^V, & \text{if } (i,j) \text{ is a blue location} \end{cases}$$

where i and j indicate the row and the column of the pixel (i; j). Next, the gradients of CH and CV are calculated as DH(i; j) = jCH(i; j)CH(i; j +2)j and DV (i; j) = jCV (i; j)CV (i+2; j)j.

Subsequently, two classifiers H(i; j) and V (i; j) are defined as the sum of the gradients DH and DV in a 5x5 neighbourhood centered at pixel (i; j). Because the strength of a directional edge is inversely proportional to the directional gradient, the weights w1 and w2 can be considered as the reciprocal of the directional gradients. We compute the horizontal and vertical gradients using the exact same method as described. The calculations of the weights w1 and w2 have two cases where the location (i; j) of the missing G pixel is an R pixel or a B pixel. Here calculating w1 and w2 at an R pixel will be considered, in which the location 5 corresponds to the location (i; j) of the missing G pixel. The calculation at a B pixel can be carried out similarly.

3.2 Interpolations of the Red and Blue Planes

Once the G plane is fully populated, it will be used to assist the subsequent interpolations of the R and B planes because the estimated G values can be considered known. It has also been seen that the directional filtering of the G plane can significantly suppress zipper artifacts, and the methods based on weighting such as EECI can better suppress false colors than the edge-directed ones (Fig. 3). Here we consider that the interpolations of the missing R and B pixel values use a weighted method. The proposed algorithm has a similar weighting scheme to EECI, but we calculate weights on the color difference planes, while EECI calculates weights on the mosaic image.

The justification is that color difference images are smoother than primary color planes. It is well known that demosaicking algorithms tend to provide satisfactory results within the smooth regions of an image. There are three different cases for the interpolation of an R pixel value (Fig.5). The missing R pixel values at the B positions will first be estimated because every B pixel has four adjacent R pixels in the diagonal directions. With the populated G plane, the color difference KR = G R can be computed at all R pixel positions. Then every missing R pixel can be estimated by the four adjacent color different values.

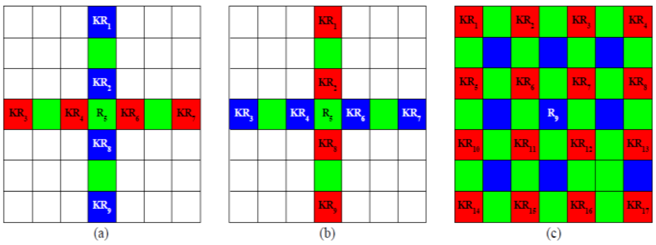

Fig. 5: Three cases of the missing red values on the central pixels. The missing red value R5 at a green location (a) and (b) ; The missing red value R9 at a blue location (c)

Where c is a constant factor adjusting the weighting effect, The principle computing the weights similar to the one.

Next the missing R pixel value at a G position will be estimated. Every G pixel has four available adjacent R pixels in horizontal and vertical directions after the missing R pixels are interpolated at the B pixel positions [Figs. 5(a) and (b)]. There into two R pixels in the horizontal or vertical direction are estimated. For example, to estimate the missing R5, then

Similarly,

$$KR_5 = \frac{w_2 * KR_2 + w_4 * KR_4 + w_6 * KR_6 + w_8 * KR_8}{w_2 + w_4 + w_6 + w_8}$$

Where $KR_i = G_i - R_i (i = 2, 4, 6, 8)$

3.3 Refinement

After the initial interpolation step, the three colour planes are fully populated and their estimates can be further refined. With the aid of the populated R and B planes, the G plane can be refined. Then the refined G plane is used to refine the R and B planes again. Only the estimated sample values will be refined and the original CFA-sampled colour values at each pixel are not altered. In addition, our refinement is only performed once. Because the refinement is to exploit the spectral correlation between colour planes, if the correlation is overused, the demosaicking results will become worse.

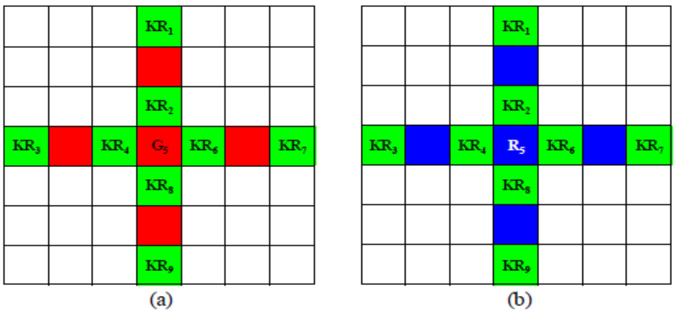

Fig. 6: The missing central pixels need be estimated. The missing green value G5 at a red location; The missing red value R5 at a blue location (b)

Refinement of the green plane: Refining the G value at an R pixel will be considered. The refinement at a B pixel can be carried out similarly. Let's refine G5 at R5 [Fig. 6(a)]. G5 = R5 +KR5, where KR5 is computed and its weights are computed.

Refinements of the red and blue planes: With the refined G plane, the R and B planes can be further refined. Since refining the B plane is similar to refining the R plane, only refining the R plane will be considered. The R values which need refining are the ones at the G or B sampling positions. With the initial populated R values, both G and B pixel positions have four adjacent R values in the horizontal and vertical directions. For every G pixel position, two of the adjacent R values are from the original CFA samples and the other two ones are estimated values. For every pixel position, four adjacent R values are all estimated values. The refinements of the R values at the G and B positions are all performed.

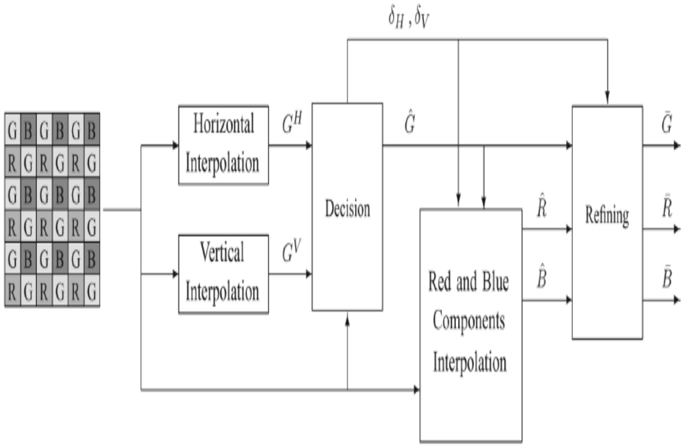

Fig.7: Complete scheme of the proposed algorithm

4. CONCLUSIONS

In this paper, a new demosaicking algorithm is proposed, which improves and combines ACPI based on weighting and DFWT based on directional filtering to estimate the missing red and blue pixels interpolated via the weighted average. In the strong edge regions, the interpolations of the missing green pixels is the done, while in the weak edge or smooth regions, the missing green pixels are interpolated via the weighted average. The interpolations of the missing red and blue pixels are done, but they are performed in the colour difference planes and use more effective weights. Experimental results showed that the proposed algorithm outperformed the recent six state-of-the-art demosaicking algorithms in terms of both subjective and objective measures over the test images.

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BIOGRAPHIES

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