Image Edges Strengthening Filter Based Color Filter Array Interpolation

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Abstract— **Most of the digital cameras use color filter arrays instead of beam splitters to capture image data so as to reduce the cost and to gain more efficiency. As a result of this, only one of the required three color samples becomes available at each pixel location and the other two needs to be interpolated. This procedure is called Color Filter Array (CFA) interpolation or demosaicing. So as to improve subjective and objective interpolation quality many demosaicing algorithms have been introduced. We propose an orientation-free edge strength filter and apply it to the demosaicing problem. Output of edge strength filter is utilized both to improve the initial green channel interpolation and to apply the constant color difference rule adaptively. This simple edge method yields visually pleasing results with high CPSNR.**

Keywords—**Color filter array (CFA) interpolation, Edge directed interpolation, orientation-free edge strength filter, demosaicing.**

I. INTRODUCTION

Multiple data samples are required at each pixel location for color images as opposed to grayscale images where each pixel is allocated with a single data sample. For the RGB image format, these data samples represent red, green and blue channels. Digital camera captures only one of these channels at each pixel location and the other two needs to be estimated to generate the complete information of color in an image. This process is called color filter array (CFA) interpolation or demosaicing. Though there are many different CFA patterns have been proposed, the most ascendant one is the Bayer pattern as shown in below Fig. 1.

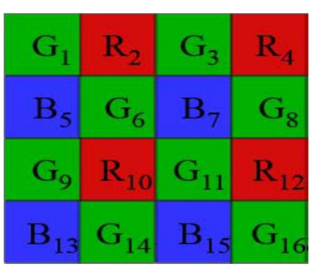

Fig1. Bayer CFA pattern.

As an important step in image processing pipeline of digital cameras, demosaicing has been interesting procedure in both academic and industry. The simple way to approach demosaicing problem is to treat color channels separately and fill in missing pixels in each channel using a spatially invariant interpolation method such as bilinear or bicubic interpolation. While this approach works fine in same related areas, it leads to color artifacts and lower resolution in regions with texture and edge structures.

Obtaining better demosaicing performance is possible by exploiting the correlation between the color channels. Spectral correlation can be designed by either constant color ratio rule [2], [3] or constant color difference rule [4], [5]. The basic assumption is that color ratio/difference is constant over a local distance inside a given object. This hypothesis is likely to break apart across boundaries; hence many demosaicing algorithms try to utilize it adaptively in one way or another.

Since the Bayer CFA pattern has twice as many green channel samples as blue and red ones, green channel suffers less from aliasing and is the natural choice as the starting point of the CFA interpolation process. In Glotzbach [6] proposed improving red and blue channel interpolation by adding high frequency components extracted from green channel to red and blue channels. In another frequency-domain approach, Gunturk used an alternating projections scheme based on strong inter-channel correlation in high frequency sub bands.

Although the main objective is to refine red and blue channels repeatedly, the same approach can also improve green channel interpolation beforehand which in turn yields better red and blue channel results. A more recent method makes several observations about color channel frequencies and suggests that filtering the CFA image as a whole instead of individual color channels should preserve better high frequency information. To estimate luminance, the method proposes a fixed 5-by-5 filter at green pixel locations and an adaptive filter for red and blue pixel locations. Estimated full resolution luminance is then used to complete missing the chrominance information.

Edge-directed green channel interpolation has been proposed early on with various direction decision rules. Several subsequent demosaicing algorithms made use of this idea. In previous methods authors proposed using variance of color differences as a decision rule while Zhang proposed making a soft decision to improve the interpolation performance of the original method. In previous method color differences along horizontal and vertical directions are treated as noisy observations of the target pixel color difference and they are combined optimally using the linear minimum mean square error estimation (LMMSE) framework. Paliy further improved directional filtering by introducing scale adaptive filtering based on linear polynomial approximation (LPA).

Several methods proposed performing interpolation in both horizontal and vertical directions and making a posteriori decision based on some criteria. Hirakawa compared local homogeneity of horizontal and vertical interpolation results and Menon used color gradients over a local window to make the direction decision.

The rest of the paper is organized as follows. Section II describes the proposed CFA interpolation algorithm. Section III presents experimental results, and finally Section IV reports the conclusion.

II. PROPOSED ALGORITHM

The basis of the proposed algorithm is the observation that the constant color difference assumption tends to fail across edges. If one can effectively utilize edge information to avoid averaging non-correlated color differences, demosaicing performance could increase dramatically.

The question at this point is how the edge information can be expressed meaningfully at the pixel level so that it is useful enough to improve demosaicing performance. Previously edge detection filters such as Sobel and Canny can tell whether an edge structure is present at a given pixel. However, they do not provide any information about the sharpness of luminance transition at that particular pixel.

We propose an edge strength filter that provides local, orientation free luminance transition information. This filter has a 3 by 3 support size. Given a grayscale input image, this could be formulated as

$$Sp6 = \frac{|P_1 - P_{11}|}{2} + \frac{|P_3 - P_9|}{2} + |P_2 - P_{13}| + |P_5 - P_7| \quad (1)$$

Where Sp6 stands for the edge strength at pixel location P6

By applying the filter to all available pixels, we get the edge strength map of the input image. Note that, although the filter result for a single pixel does not provide any edge direction information, but it provides the relationship between neighboring pixel and it results in an edge orientation in that neighborhood.

The proposed filter is very useful for finding edges in a grayscale image. However, a mosaicked image only has one of the three color channels available for every pixel location and it certainly does not have complete luminance information at any pixel. That is why; the edge strength filter can only be applied to a mosaicked image by making an approximation. Rather than trying to estimate luminance information and taking estimated luminance differences of neighboring pixels, we take the difference in terms of the available color channel for each pixel pair. If we consider in the case of red channel, red as center pixel then the diagonal differences will come from the blue channel and the rest from the green channel

$$S_{R_{10}} = \frac{|B_5 - B_{15}|}{2} + \frac{|B_7 - B_{13}|}{2} + |G_6 - G_{14}| + |G_6 - G_{14}| \quad (2)$$

The edge strength for green and blue pixels will be calculated in the same way. The edge strength map can be obtained from the mosaicked input image will help us both in initial green channel interpolation stage and in subsequent green channel update.

A. Green Channel Interpolation

We propose making a hard decision based on the edge strength filter described above. For this purpose, every green pixel to be interpolated (red or blue pixel in the mosaicked image) is marked either horizontal or vertical by comparing the edge strength differences along each direction on a local window. For a 5 by 5 window size, horizontal and vertical difference costs can be formulated as follows:

$$H_{i,j} = \sum_{m=-2}^{2} \left(\sum_{n=-2}^{1} (S_{i+m,j+n} - S_{i+m,j+n+1}) \right)$$
$$V_{i,j} = \sum_{m=-2}^{1} \left(\sum_{n=-2}^{2} (S_{i+m,j+n} - S_{i+m+1,j+n}) \right) \quad (3)$$

Where $(S_{i,j})$ is the edge strength filter output at pixel location (i,j), and $H_{i,j}$ and $V_{i,j}$ represent the total horizontal and vertical costs, respectively.

The target pixel will be labeled horizontal if horizontal cost is less than vertical and vice versa. The logic behind this decision scheme is that if there happens to be a horizontal edge in a given neighborhood, then the strength in edges differs between vertical neighbors than those of horizontal neighbors. Once the pixels are labeled, the robustness of the direction decision can be improved by relabeling them based on their neighbor’s directions. For example, considering the closest 8 neighbors of a target pixel and the pixel which we consider, it will be labeled horizontal only if more than 4 of those 9 pixels are initially labeled horizontally. Based on the final direction label, interpolated green channel is as follows:

$$\tilde{G}_{i,j} = \begin{cases} B_{i,j} + \frac{G^{H}{}_{i,j} - B_{i,j}}{2} + \frac{G_{i,j-1} - B^{H}{}_{i,j-1}}{4} + \frac{G_{i,j+1} - B^{H}{}_{i,j+1}}{4}, & IF\ Horizontal \\ B_{i,j} + \frac{G^{V}{}_{i,j} - B_{i,j}}{2} + \frac{G_{i-1,j} - B^{V}{}_{i-1,j}}{4} + \frac{G_{i+1,j} - B^{V}{}_{i+1,j}}{4}, & IF\ Verical \end{cases} \quad (4)$$

Where directional estimations are calculated by

$$G^{H}{}_{i,j} = \frac{G_{i,j-1} + G_{i,j+1}}{2} + \frac{2 * B_{i,j} - B_{i,j-2} - B_{i,j+2}}{4}$$
$$G^{V}{}_{i,j} = \frac{G_{i-1,j} + G_{i+1,j}}{2} + \frac{2 * B_{i,j} - B_{i-2,j} - B_{i+2,j}}{4}$$
$$B^{H}{}_{i,j} = \frac{B_{i,j-1} + B_{i,j+1}}{2} + \frac{2 * G_{i,j} - G_{i,j-2} - G_{i,j+2}}{4}$$
$$B^{v}{}_{i,j} = \frac{B_{i-1,j} + B_{i+1,j}}{2} + \frac{2 * G_{i,j} - G_{i-2,j} - G_{i+2,j}}{4} \quad (5)$$

Estimation for red pixel locations from green channel is performed simply by replacing B's with R's in the equations above.

B. Green Channel Update

The second step of the proposed algorithm is updating the green channel. In this we make use of the constant color difference assumption combined with edge strength filter to improve the initial green channel interpolation while avoiding averaging across edge structures. For updating every green pixel, we select the closest four neighbors with available color difference estimates are considered. We expect the differences in strengthening of edges between two pixels to be large across edges. That is the reason why weight for each neighbor is inversely correlated with the total absolute edge strength difference in its direction. In other words, a neighbor contributes less to the update result if there happens to be a strong edge between the target pixel and itself. Suppose that we are updating the green channel value at a blue pixel location:

$$D_1 = |S_{i,j} - S_{i-1,j}| + |S_{i-1,j} - S_{i-2,j}| + |S_{i-2,j} - S_{i-3,j}| + C_1$$
$$D_2 = |S_{i,j} - S_{i,j-1}| + |S_{i,j} - S_{i,j-2}| + |S_{i,j-2} - S_{i,j-3}| + C_1$$
$$D_3 = |S_{i,j} - S_{i,j+1}| + |S_{i,j+1} - S_{i,j+2}| + |S_{i,j+2} - S_{i,j+3}| + C_1$$
$$D_4 = |S_{i,j} - S_{i+1,j}| + |S_{i+1,j} - S_{i+2,j}| + |S_{i+2,j} - S_{i+3,j}| + C_1$$
$$M_1 = D_2 * D_3 * D_4$$
$$M_2 = D_1 * D_3 * D_4$$
$$M_3 = D_1 * D_2 * D_4$$
$$M_4 = D_1 * D_2 * D_3$$

$$\tilde{G}_{i,j} = B_{i,j} + W * (\tilde{G}_{i,j} - B_{i,j}) + (1 - W) * \left[\frac{M_1}{M_{Total}}(\tilde{G}_{i-2,j} - B_{i-2,j}) + \frac{M_2}{M_{Total}}(\tilde{G}_{i,j-2} - B_{i,j-2}) + \frac{M_3}{M_{Total}}(\tilde{G}_{i,j+2} - B_{i,j+2}) + \frac{M_4}{M_{Total}}(\tilde{G}_{i+2,j} - B_{i+2,j})\right] \quad (6)$$

Again, green channel values at red pixel locations are updated in the same way by replacing B's with R's in the equations above. $\tilde{G}_{i,j}$ Stands for updated green channel result while $\tilde{G}_{i,j}$ is the initial green channel interpolation. C_1 is a nonzero constant to avoid zero denominators. W_1 is the weight for the initial color difference estimation and W_2 is the neighbors' contribution to the green channel update. Updating green channel improves PSNR and reduces color artifacts. However, zipper artifacts become more prominent as the number of updates increase. An experiment on test images recommends that one or two green channel updates are adequate.

The performance of updated green channel can be improved further by making W_1 adaptive for each pixel by checking the total absolute difference between the closest known green pixels. The idea is that green channel update should be more aggressive if there happens to be a lot of difference between known green pixels in that neighborhood because initial interpolation is more likely to fail in such areas. The update equations with adaptive weights are as follows,

$$\tilde{G}_{i,j} = B_{i,j} + (W - A_{i,j})(\tilde{G}_{i,j} - B_{i,j}) + (1 - W + A_{i,j}) * \left[\frac{M_1}{M_{Total}}(\hat{G}_{i-2,j} - B_{i-2,j}) + \frac{M_2}{M_{Total}}(\hat{G}_{i,j-2} - B_{i,j-2}) + \frac{M_3}{M_{Total}}(\hat{G}_{i,j+2} - B_{i,j+2}) + \frac{M_4}{M_{Total}}(\hat{G}_{i+2,j} - B_{i+2,j})\right]$$
$$A\_(i,j) = min((|G\_(i-1,j) - G\_(i,j+1)| + |G\_(i,j+1) - G\_(i+1,j)| + |G\_(i+1,j) - G\_(i,j-1)| + |G\_(i,j-1) - G\_(i-1,j)|)/4, C\_2) \quad (7)$$

C. Red and Blue Channel Interpolation

Once the green channel interpolation is finalized, we fill in red and blue channels using constant color difference assumption. For red channel interpolation at blue pixels and blue channel interpolation at red pixels, diagonal neighbors are used adaptively based on green channel gradients in both directions

$$M_1 = |\tilde{G}_{i-2,j-2} - \tilde{G}_{i,j}| + |\tilde{G}_{i-1,j-1} - \tilde{G}_{i+1,j+1}| + |\tilde{G}_{i,j} - \tilde{G}_{i+2,j+2}|$$
$$M_2 = |\tilde{G}_{i-2,j+2} - \tilde{G}_{i,j}| + |\tilde{G}_{i-1,j+1} - \tilde{G}_{i+1,j-1}| + |\tilde{G}_{i,j} - \tilde{G}_{i+2,j-2}| \quad (8)$$

If coordinate (i,j), is a red pixel location, blue channel estimation is calculated by

$$\tilde{B}_{i,j} = \tilde{G}_{i,j} - \frac{M_2 * (\tilde{G}_{i-1,j-1} - B_{i-1,j-1} + \tilde{G}_{i+1,j+1} - B_{i+1,j+1})}{2 * (M_1 + M_2)} - \frac{M_1 * (\tilde{G}_{i-1,j+1} - B_{i-1,j+1} + \tilde{G}_{i+1,j-1} - B_{i+1,j-1})}{2 * (M_1 + M_2)} \quad (9)$$

The equations are similar for red channel estimation at a blue pixel location. For red and blue channel estimation at green pixels, we employ bilinear interpolation over color differences since considered adaptive approaches do not provide any performance gain. Here, we consider only the closest two neighbors for which the original pixel value available are used

$$\tilde{B}_{2i,2j} = G_{2i,2j} - \frac{(\tilde{G}_{2i-1,2j} - B_{2i-1,2j}) + (\tilde{G}_{2i+1,2j} - B_{2i+1,2j})}{2}$$

$$\tilde{B}_{2i+1,2j+1} = G_{2i+1,2j+1} - \frac{(\tilde{G}_{2i+1,2j} - B_{2i+1,2j}) + (\tilde{G}_{2i+1,2j+2} - B_{2i+1,2j+2})}{2}$$

By the end of this step, we filled in all the missing color channel values in the input image. We utilized a simple edge strength filter both to determine the initial green channel interpolation direction and to avoid applying constant color difference rule across edge structures.

II. EXPERIMENTAL RESULTS

The proposed algorithm is tested on the Kodak images. The test set was consisting of 6 images with 512-by-768 pixel resolution. The images are first down sampled in Bayer CFA pattern and then interpolated back to three channels using proposed algorithm. The interpolated images are compared to the original images and results are reported in terms of CPSNR error measure. Pixels within 10 pixel distance from the border are excluded from the calculations.

The proposed method requires 376 additions, 64 multiplications, 52 absolute, 36 shifts, and 10 division operations for every 2 by 2 GRBG input pixel block. The highest performing IGD method requires between 266 and 374 operations for the same 2 by 2 block.

A detailed complexity comparison table can be found in [19]. Challenging image regions are presented in Figures4, 5, 6 and 7.for visual quality comparison. In fig.2 we consider Kodak image picture this picture is given with some additive noise shown in fig.3 and these two images are applied with color filter array shown in fig4&5.The proposed algorithm is applied in fig.7.The proposed solution performance under noise is compared against three highest performing methods.


Fig 2.Original Image


Fig 3.Noisy Image

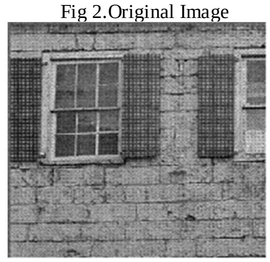
Fig 4.Original CFA Image

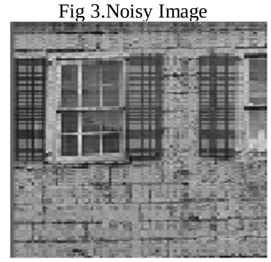
Fig 5.Noisy CFA Image

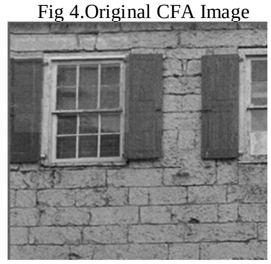
Fig 6.Denoised Image

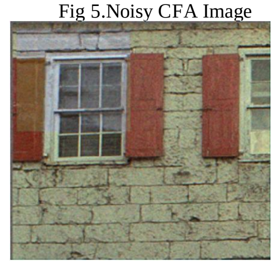
Fig 7. Reconstructed Interpolated Image

IV. CONCLUSION

We presented a simple edge strength filter and applied it to the CFA interpolation problem. Edge strength filter helped us identify regions where constant color difference assumption is likely to fail which in turn lead to improved demosaicing performance. Further research efforts will focus on improving the interpolation results by exploiting spectral correlation more effectively and applying the proposed edge strength filter to other image processing problems.

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