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Multiscale Gradients based directional demosaicing

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Abstract:
Single sensor digital cameras capture one color value for every pixel location. The remaining two color channel values need to be estimated to obtain a complete color image. This process is called demosaicing or Color Filter Array (CFA) interpolation. We propose a directional approach to the CFA interpolation problem that makes use of multiscale color gradients .The relationship between color gradients on different scales is used to generate signals in vertical and horizontal directions. We determine how much each direction should contribute to the green channel interpolation based on these signals. The proposed method is easy to implement since it isnon iterative and threshold free. Experiments on test images show that it offers superior objective and subjective interpolation quality.
Index Terms -Demosaicing, Color filter array interpolation, Multiscale color gradient, directional interpolation.

I. INTRODUCTION

Most digital cameras employ single sensor designs because using multiple sensors coupled with beam splitters for each pixel location is costly in hardware. This design choice necessitates the use of color filter arrays. The color channel layout on a color filter array determines which channel will be captured at each pixel location. Many different CFA layouts have been proposed but the Bayer CFA pattern is the most commonly used design[1].The CFA pattern layout plays an important role in the design of a CFA interpolation algorithm.

Demosaicing is an important part of the image processing pipeline in digital cameras. The failure of the employed demosaicing algorithm can degrade the overall image quality considerably. The simplest way to address the demosaicing problem would be to treat each color channel separately and interpolate. The color channel layout for the Bayer CFA pattern is shown in Figure1. The quality can be improved by applying the interpolation over color differences to take advantage of the correlation between the color channels. However, the lack of spatial adaptiveness would still limit the interpolation performance.The gradients are useful for extracting directional data from digital images.Several demosaicing methods include the integrated gradients.

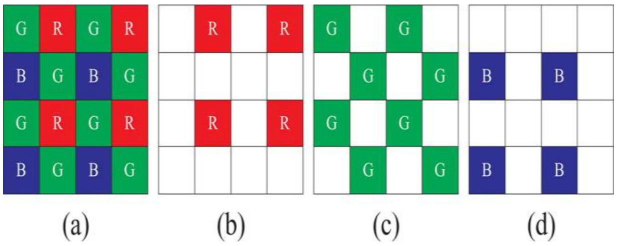

Figure1. Bayer color filter array pattern and its (b) red,
(c) green and (d) blue samples

While it is possible to use simple linear interpolation techniques to complete the missing color channel information, such non adaptive approaches lead to low quality output with false color artifacts and blurriness. In addition to the available spatial correlation, there is a spectral correlation between the color channels and any high quality CFA interpolation algorithm needs to take advantage of this information source somehow.Hamilton et al. proposed adaptively interpolating the green channel in horizontal or vertical directions or a combination of both, based on directional classifiers and thresholds [2].The idea of using available red and blue channel pixels in initial green channel interpolation is borrowed by many subsequent methods. A possible area for improvement is to come up with better classifiers that can lead to a more accurate direction decision. Variance of color differences is used to make a hard interpolation direction decision in [3], while linear minimum mean-square error framework is employed to combine directional estimates in [4].

Another interesting approach is to interpolate the green channel in both directions and then to make a posteriori decision based on sum of gradients in each direction[5].The demosaicing problem has been studied from many other angles. Glotzbach et al.proposed a frequency domain approach where they extracted high frequency components from the green channel and used them to improve red and blue channel interpolation[6]. he full range of demosaicingGunturk et al. used the strong spectral correlation between high frequency sub bands to develop an alternating projections method [7].

A comprehensive list of demosaicing approaches, experimental results, and observations are presented in a recent survey paper[8].An early demosaicing method proposed Adaptive color plane interpolation in single sensor color electronic camera used derivatives of chrominance samples in initial green channel interpolation, and this idea is borrowed by many subsequent algorithms. Various demosaicing algorithms proposed directional interpolation with different decision rules. For instance Color demosaicing using variance of color differences used variance of color differences to make a hard direction decision. On the other hand, Color demosaicking via directional linear minimum mean square-error estimation proposed a soft direction decision based on the Linear Minimum Mean Square Error Estimation (LMMSE) framework. Here, the directional color differences are considered as noisy observations of the actual color difference and they are combined optimally. Spatially adaptive color filter array interpolation for noiseless and noisy data improved this directional approach with scale adaptive filtering based on local polynomial approximation (LPA). Another interesting directional approach is to perform interpolation in both directions and then make a posteriori decision. Adaptive homogeneity-directed demosaicing algorithm used local homogeneity of the directional interpolation results and Demosaicing with directional filtering and a posteriori decision used color gradients over a local window as the decision criteria. The demosaicing problem has been studied in the frequency domain as well. Another method proposed using high frequency components extracted from green channel to improve red and blue channel components that are more susceptible to aliasing. Color plane interpolation using alternating projections proposed an alternating projections scheme using the strong inter-channel correlate on in high frequency sub bands. Since the method is iterative, it required a high number of calculations. Another method Adaptive filtering for color filter array demosaicking proposed filtering the input mosaiced color components together to preserve the high frequency components better.

The rest of the paper is organized as follows. Section 2 gives some background information and describes the proposed method in detail. Section 3 presents experimental results, and section 4 gives a brief discussion.

II. PROPOSED ALGORITHM

A. Algorithm background

We have proposed a directional CFA interpolation method that uses the color difference gradients have more features to combine color difference estimates from various directions based on the ratio of total absolute values of horizontal and vertical color difference. The steps are illustrated below.

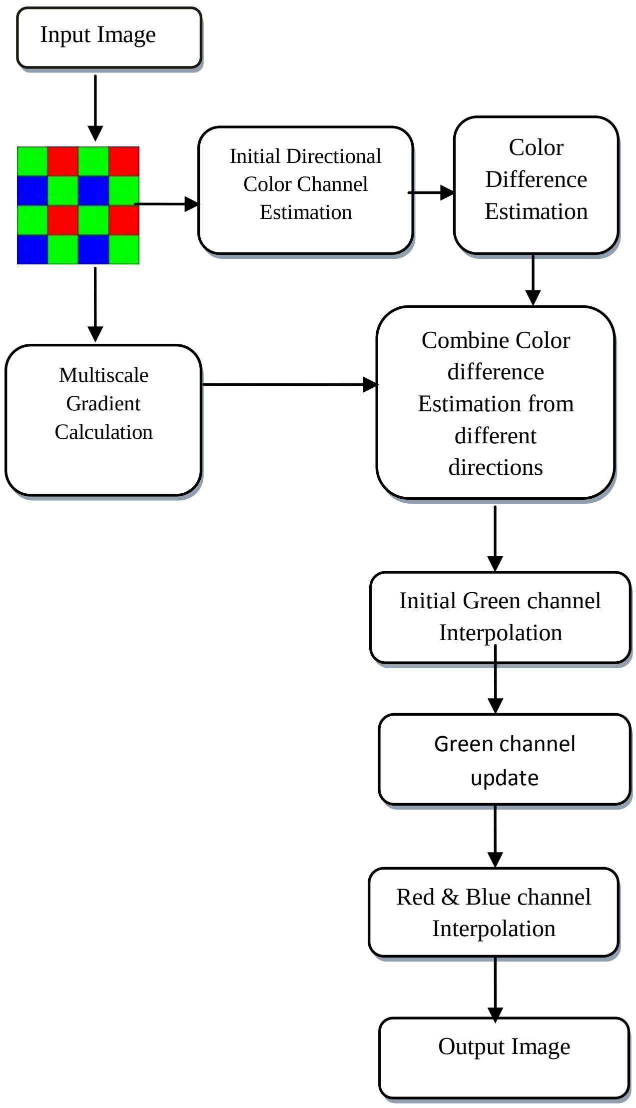

Fig: 2System design

Most digital cameras use color filter arrays and this design choice leads to the capture of only a subset of the image data. The color channels filtered out by the CFA pattern layout needs to be estimated using the recorded channel values. The simplest way to address the demosaicing problem would be to treat each color channel separately and interpolate the missing color channels.

The first step is to get initial directional color channel estimates .For red & green rows and columns, directional estimates are calculated for missing pixel values are:

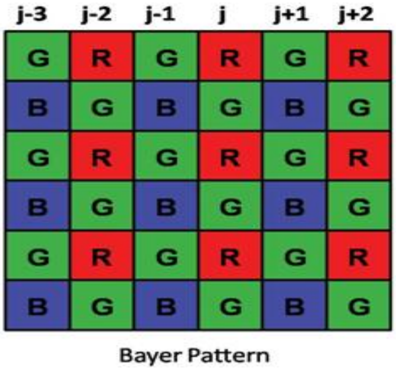

Fig: 3 Bayer mosaic pattern

For red & green rows and columns in the input mosaic image, the directional estimates for the missing red and green pixel values are calculated. For blue & green rows and columns in the input mosaic image, the directional estimates for the missing blue and green pixel values are calculated. Here we are calculating horizontal and vertical color channel estimates. The directional color channel estimates for the missing Green pixel values are,

$$G^H(i,j) = \frac{G(i,j-1)+G(i,j+1)}{2} + \frac{2.R(i,j)-R(i,j-2)-R(i,j+2)}{4}$$

$$G^V(i,j) = \frac{G(i-1,j)+G(i+1,j)}{2} + \frac{2.R(i,j)-R(i-2,j)-R(i+2,j)}{4} \quad (1)$$

The directional color channel estimates for the missing Red pixel values are,

$$R^H(i,j) = \frac{R(i,j-1)+R(i,j+1)}{2} + \frac{2.G(i,j)-G(i,j-2)-G(i,j+2)}{4}$$

$$R^V(i,j) = \frac{R(i-1,j)+R(i+1,j)}{2} + \frac{2.G(i,j)-G(i-2,j)-G(i+2,j)}{4} \quad (2)$$

Where H and V denote horizontal and vertical directions(i,j) is the pixel location. Now we have a true color channel value. Next take the color difference estimate:

$$C^H_{g,r}(i,j) = \begin{cases} G^H(i,j) - R(i,j), & \text{if G is interpolated} \\ G(i,j) - R^H(i,j), & \text{ifRisinterpolated} \end{cases}$$

$$C^V_{g,r}(i,j) = \begin{cases} G^V(i,j) - R(i,j), & \text{if G is interpolated} \\ G(i,j) - R^V(i,j), & \text{ifRisinterpolated} \end{cases} \quad (3)$$

This eq(3) is similar for blue & green rows and columns. We propose a more effective approach to directional interpolation, where the decision of the most suitable directionof interpolation is made on the basis of the reconstructed green component only. We proposed a directional CFA interpolation method that uses color difference gradients in [9]. We have been looking for ways to improve its performance and examining color difference gradients on the pixel level was one of areas that we focused on. The horizontal color difference gradient on a red &green row is given as follows:

$$D^H(i,j) = |C^H(i,j-1) - C^H(i,j+1)|$$

$$D^V(i,j) = |C^V(i-1,j) - C^V(i+1,j)| \quad (4)$$

The color difference gradients calculated in eq(4) are used to find weights for each direction. Next the absolute color difference gradients of available color channels are replaced to the multiscale and which is doing same operations. The color difference gradient corresponds to taking the difference between the available color channel values two pixels away from the target pixel, doing the same operation in terms of the other color channel by using simple averaging, and then finding the difference between these two operations .If these two color channels are changing in parallel with each other along this direction, then the resulting absolute value would be small. On the other hand, if there is an abrupt color change, then the result would be large and the color difference estimate along this direction would be given a small weight in combined color difference calculation. Our color difference gradient corresponds to taking the difference between the available color channel values two pixels away from the target pixel, doing the same operation in terms of the other color channel by using simple averaging, and then finding the difference between these two operations. It could be argued that the performance of such an algorithm relies on its ability to successfully combine directional estimates.

Here we take the difference between the available color channel values one pixel away from the target pixel.

$$D^h(i,j) = |\frac{G(i,j+1) - G(i,j-1)}{2} - \frac{R(i,j+2) - R(i,j-2)}{4}| \quad (5)$$

Next these equations combine the color difference estimates from various directions. The easiest way of doing that is to optimize the normalizing terms (N) in the denominators. The final multiscale gradient equation for red green rows and columns can be given as follows:

$$L^H(i,j) = |\frac{G(i,j+1) - G(i,j-1)}{2} - \frac{R(i,j+2) - R(i,j-2)}{N1} + \frac{G(i,j+3) - G(i,j-3)}{N2} - \frac{R(i,j+4) - R(i,j-4)}{N3}|$$

$$L^V(i,j) = |\frac{G(i+1,j) - G(i-1,j)}{2} - \frac{R(i+2,j) - R(i-2,j)}{N1} + \frac{G(i+3,j) - G(i-3,j)}{N2} - \frac{R(i+4,j) - R(i-4,j)}{N3}| \quad (6)$$

B.Initial Green Channel Interpolation

The first step of the proposed algorithm is to interpolate the missing green channel pixels. We perform this interpolation adaptively using the multiscale color gradients equation derived above.In addition to the horizontal and vertical pixel value and color difference estimations described in equations (2)and(3).Next we combine the directional color difference adaptively:

$$\delta_{g,r}(i,j) = \left[w_V . f . C^V_{g,r}(i-1:i+1,j) + w_H . C^H_{g,r}(i,j-1:j+1) . f'\right] / w_C$$

$$w_C = w_V + w_H$$

$$f = [1/4 \;\; 2/4 \;\; 1/4] \quad (7)$$

The weights for horizontal and vertical directions(w_H , w_V) are calculated by adding multiscale color gradients over a local window.For a local window size of 5 by 5,the weight for each direction is calculated as follows in eq(8),

$$w_V = 1/\left(\sum_{m=i-2}^{i+2}\sum_{n=j-2}^{j+2} G^V(m,n)\right)^2 + 1$$

$$w_H = 1/\left(\sum_{m=i-2}^{i+2}\sum_{n=j-2}^{j+2} G^H(m,n)\right)^2 + 1 \quad (8)$$

The division operation can be avoided by defining the weights as the denominators and exchanging them. This section concentrates on estimating missing green pixels from known green and red pixel values using the green-red row of Bayer pattern. The same technique is used to estimating missing green pixels from known green and blue pixels. We have directional color difference estimates around every green pixel to be interpolated.

Fig. 4 24 image Kodak test set

C. Green Channel Update

After the initial green channel interpolation ,we update the results using directional multiscale gradients again, except we evaluate all the directions separately .It is used to improve the green channel results. The four neighbors of the target pixel has its own weight as follows:

$$w_N = 1/\left(\sum_{m=i-4}^{i}\sum_{n=j-1}^{j+1} L^V(m,n)\right)^2 + 1$$

$$w_S = 1/\left(\sum_{m=i-2}^{i+4}\sum_{n=j-1}^{j+1} L^V(m,n)\right)^2 + 1$$

$$w_E = 1/\left(\sum_{m=i-1}^{i+1}\sum_{n=j-4}^{j} L^V(m,n)\right)^2 + 1$$

$$w_W = 1/\left(\sum_{m=i-1}^{i+1}\sum_{n=j}^{j+4} L^V(m,n)\right)^2 + 1$$

$$w_T = w_N + w_S + w_E + w_W$$

(9)

In eq (9) w is a number between 0 and 1 that determines how aggressive the update is. The weight for each direction (w_N, w_S, w_E, w_w) is calculated by summing multiscale color gradients over a local window .Assuming a 3 by 5 window for horizontal and a 5 by 3 window for vertical components. Here the directional color difference estimates are updated.

$$\gamma_{g,r}(i,j) = \delta_{g,r}(i,j).(1-w) + [w_N.\delta_{g,r}(i-2,j) + w_S.\delta_{g,r}(i+2,j) + w_E.\delta_{g,r}(i,j-2) + w_N.\delta_{g,r}(i,j+2)].w/w_T$$

(10)

Finally the updated color difference estimate is added to the available target pixel to obtain the green channel estimate:

$$G'(i,j) = \gamma_{g,r}(i,j) + R(i,j)$$

$$G'(i,j) = \gamma_{g,r}(i,j) + B(i,j) \qquad (11)$$

D. Red and Blue Channel Interpolation

For red and blue channel interpolation, we keep the same approach that we employed in[9]. Red pixel values at blue locations and blue pixel values at red locations are interpolated using the filter that was proposed.

$$P_{rb} = \begin{bmatrix} 0 & 0 & -1 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 10 & 0 & 10 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 10 & 0 & 10 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & -1 & 0 & 0 \end{bmatrix} . \frac{1}{32}$$

Where $\otimes$ denotes element-wise matrix multiplication and then summation of elements.

$$R'(i,j) = G'(i,j) - \gamma(g,r)\,(i-3:i+3, j-3:j+3,j) \otimes Prb$$

$$B'(i,j) = G'(i,j) - \gamma(g,b)(i-3:i+3, j-3:j+3,j) \otimes Prb$$

(12)

For red and blue pixels at green locations,We make use of the multiscale color gradients again. The horizontal and vertical estimations are combined adaptively using the directional weights (w_H, w_V) defined in equation (12). The immediate vertical neighbors of a green pixel are either red or blue pixels. For the red pixel case the interpolation is carried out as follows:

$$R'(i,j) = G(i,j) - \frac{w_V * (G'_{i-1,j} - R_{i-1,j} + G'_{i+1,j} - R_{i+1,j})}{2*(w_v + w_H)} - \frac{w_H * (G'_{i,j-1} - R'_{i,j-1} + G'_{i,j+1} - R'_{i,j+1})}{2*(w_v + w_H)}$$

$$B'(i,j) = G(i,j) - \frac{w_V * (G'_{i-1,j} - B'_{i-1,j} + G'_{i+1,j} - B'_{i+1,j})}{2*(w_v + w_H)} - \frac{w_H * (G'_{i,j-1} - B_{i,j-1} + G'_{i,j+1} - B_{i,j+1})}{2*(w_v + w_H)} \quad (13)$$

By the end of thiseq(13), all the missing values are estimated and the full color image is reconstructed.

III. EXPERIMENTAL RESULTS

We tested the proposed algorithm on the 12 image Kodak test set featured in [8]. The results in terms of CPSNR are compared to the three highest performing methods in a recent survey paper [8], and to the method the served as the starting point of the proposed algorithm [9]. These methods are Gradient Based Threshold Free CFA(GBTF) [9], Local Polynomial Approximation (LPA) [10], Directional Linear Minimum Mean Square-Error Estimation (DLMMSE) [4], and variances of color differences (VCD) [3]. The proposed algorithm has the best CPSNR for every image in the test set. It outperforms the closest method(GBTF)by 0.46 dB on average. The comparison results are summarized in Table 1 and a sample image region is shown in Figure 4.

No	VCD	DL	LPA	GBTF	Prop
1.	44.09	44.33	44.91	44.67	45.06
2.	41.45	41.62	42.31	42.45	42.84
3.	43.17	43.28	43.91	43.82	44.46
4.	37.70	37.30	38.49	38.34	38.94
5.	44.21	44.14	44.51	44.70	45.09
6.	44.04	41.17	41.61	41.97	42.46
7.	41.74	44.80	44.91	45.45	45.85
8.	41.66	42.01	42.49	42.79	43.20
9.	42.42	42.56	42.79	43.18	43.54
10.	40.58	40.53	40.99	41.18	41.78
11.	39.65	39.84	39.98	40.30	40.55
12.	37.30	37.76	37.67	37.87	38.02
Avg	41.50	41.61	42.05	42.23	42.65

Table: 1 Comparison of CPSNR values for different demosaicing methods.

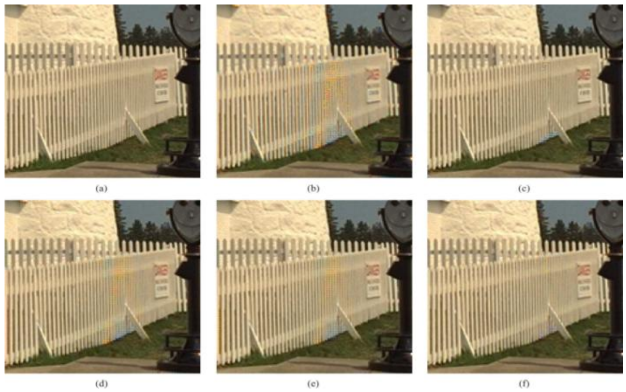

Fig: 5 Fence region from images no.7 (a)Original(b)VCD (c) DLMMSE (d) LPAICI (e) GBTF (f) Proposed

IV.CONCLUSION

In this paper, we have demonstrated that the relationship between color gradients at different scales can be used to develop a high quality CFA interpolation method that is easy to implement. Experimental results show that the proposed method out performs other available algorithms by a clear margin in terms of CPSNR. Further research efforts can focus on improving the results and applying the multiscale gradients idea to other image processing problems

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