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Sharp Color Edge Preservation using HOI

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ABSTRACT
Color Filter Array Demosaicking is an interpolation process to determine missing color pixel values when a single-sensor digital camera is used for color image capture. This paper focuses on sharp color edge preservation of demosaicked image using a second order interpolation technique. Several demosaicking methods have already been developed, e.g., Bi linear, Constant-Hue-Based, Edge-Directed etc. Here, a new method based on the application of Taylor series is proposed. The missing green values are interpolated using Taylor series expansion because of its accuracy and simplicity. Color edges are sharp boundaries between two distinct colors. To avoid the blurring of an edge, interpolants are first estimated in four opposite directions so that no interpolation is carried out across an edge. Then a classifier based on an edge orientation map is used to assign weights for a edge preserving weighted median filter, which is used to determine the output. Weighted median filter is used to produce an output from the four interpolants in order to preserve sharp color edges and produce minimal color artifacts in the output image. Thus, the estimates obtained are more accurate than already existing methods due to the inclusion of higher-order terms. The spectral correlations refer to the fact there is a high correlation between the green and red/blue pixel values within a local neighborhood. Higher order approximation is required for the green plane only .For red and blue planes, first-order approximation is adequate because they are under sampled and the human visual system is less sensitive to red and blue. So first-order interpolation is sufficient.

It has been shown that proposed method outperforms visually and quantitatively with image quality measures, when compared with other existing methods.

Keywords
Demosaicking, Weighted median filter, Higher order interpolation, CFA.

1. INTRODUCTION
Color Filter Array demosaicking refers to the process of interpolating missing color pixel values when a single-sensor digital camera is used for color image capture. The Bayer pattern, as shown in figure 1, is the most common color filter array used, which came from the name of its inventor Bryce Bayer. The green color is sampled at twice the rate of the red and blue values. This is due to the peak sensitivity of the human visual system which lies in the green spectrum.

Various techniques have been available to interpolate the missing color pixel values. Bilinear method is the simplest demosaicking method, which fills missing color values with weighted averages of their neighboring pixel values. Although bilinear interpolation requires less computation cost and easy implementation, it introduces

G_{11}	R_{12}	G_{13}	R_{14}	G_{15}	R_{16}	G_{17}	R_{18}
B_{21}	G_{22}	B_{23}	G_{24}	B_{25}	G_{26}	B_{27}	G_{28}
G_{31}	R_{32}	G_{33}	R_{34}	G_{35}	R_{36}	G_{37}	R_{38}
B_{41}	G_{42}	B_{43}	G_{44}	B_{45}	G_{46}	B_{47}	G_{48}
G_{51}	R_{52}	G_{53}	R_{54}	G_{55}	R_{56}	G_{57}	R_{58}
B_{61}	G_{62}	B_{63}	G_{64}	B_{65}	G_{66}	B_{67}	G_{68}
G_{71}	R_{72}	G_{73}	R_{74}	G_{75}	R_{76}	G_{77}	R_{78}
B_{81}	G_{82}	B_{83}	G_{84}	B_{85}	G_{86}	B_{87}	G_{88}

Fig 1: An 8X8 window of the Bayer pattern.

various degrees of color artifacts and over smoothing of sharp edges, which results edge blurring. Another demosaicking method known as Constant-Hue-Based Interpolation, is based on the assumption that color differences or hue are locally constant because there is a high interchannel correlation within an object of an image. But, this assumption is valid only within the boundary of an object and it gets violated across edges. So this method, based on inter-channel color differences cannot perform satisfactorily around sharp edges, where the assumed spectral correlation does not necessarily hold. Here by exploiting this spatial correlation among neighboring pixels, these methods aim to perform color interpolation along image edges, rather than across them. Some demosaicking methods use gradient values to select preferred edge direction to perform interpolation. This is to reduce edge artifacts and enhance image sharpness. Any errors in the gradient estimation will result color artifacts in the output image. Another efficient edge-directed technique is proposed in where the edge estimation is performed by analyzing the variances of the color differences, in order to exploit the correlation between the color components to introduce a hard-decision rule and individuate the best direction for the interpolation. Many demosaicking methods use edge-interpolated techniques [2], where the interpolation is performed along the edges rather than across them. But these methods produce poor outputs mainly due to errors in edge detection. Edge detection errors will result poor outputs such as false colors and blurred edges. Several edge classifiers are proposed to identify the best directions for interpolating the missing color values. In general, performance of these methods is limited by the accuracy of their estimation algorithms.

Since a huge number of approaches has been proposed, I subdivide them in five groups, namely heuristic methods, algorithms based on directional interpolations, frequency-domain approaches, wavelet based methods, and reconstruction techniques. Here I propose a non iterative demosaicking algorithm based on directional interpolations to determine the missing color values will produce minimal color artifacts and will outperform other existing demosaicking algorithms for most types of images.

This proposed method consists of two parts. In the first half, a second order interpolation algorithm, based on Taylor series is used to determine four estimates of the missing color value along four different directions. To check whether the series converges towards f(x), one normally uses estimates for the remainder term of Taylor's theorem. A function is analytic if and only if a power series converges to the function then the coefficients in that power series are then necessarily the ones given in the Taylor series formula. The Taylor series is important in three aspects. First, it is easy to implement because the differentiation and integration of power series can be performed term by term. Second, an analytic function can be uniquely extended to a holomorphic function defined on an open disk in the complex plane, which makes the whole machinery of complex analysis available. Third, the truncated series can be used to approximate values of the function near the point of expansion. Also the missing values are calculated using Taylor series expansion because of its accuracy and simplicity. In the later half, a classifier based on an edge orientation map is used to assign weights for a edge preserving weighted median filter, which is used to determine the output. Weighted median filter is used to produce an output from the four interpolants in order to preserve sharp color edges and produce minimal color artifacts in the output image.

Extrapolation is filling in data points beyond the data that already have (extending the data). For example fitting a curve to the data that already have using an equation, then extending that line beyond the first and last points helps to estimate values (or extrapolate them) beyond the measured data. Interpolation is filling in data points between the data that already have. For example - drawing a line (fitting a curve) from the first data point to the last point allows estimating data points between those two extremes (or between any data points that you have). i.e. 'filling in between'.

Here a second-order interpolation method with high accuracy is used to determine four directional estimates of the missing color pixel. Each of the directional estimates is obtained by interpolating the spectral correlations among neighboring pixels along that particular direction. In this way, the estimates obtained are more accurate than already existing methods due to the inclusion of second-order terms. The spectral correlations refer to the fact there is a high correlation between the green and red/blue pixel values within a local neighborhood.

Based on the Bayer pattern, each missing green value is surrounded by four known green values located in the left, right, top and bottom directions. Hence, to determine the missing values in the green plane, the estimates for the missing green value are interpolated in the four same directions. The green plane is interpolated first as it contains the most samples, twice as many as the red or blue samples. The approximation is carried out using Taylor series. The missing green values are calculated using Taylor series expansion because of its accuracy and simplicity. So Taylor series is used to interpolate the green value pixel at position x along the edge from pixels on the left-hand side of it, where g(x) is the value of a green pixel at location x. The Bayer pattern and equations for green interpolation are given as follows:

$$G^L_{45} = G_{44} + 1/2(B_{45} - B_{43}) + 1/8(G_{46} - 2G_{44} + G_{42}) \quad (1)$$

$$G^R_{45} = G_{46} + 1/2(B_{45} - B_{47}) + 1/8(G_{44} - 2G_{46} + G_{48}) \quad (2)$$

$$G^T_{45} = G_{35} + 1/2(B_{45} - B_{25}) + 1/8(G_{56} - 2G_{35} + G_{15}) \quad (3)$$

$$G^B_{45} = G_{55} + 1/2(B_{45} - B_{65}) + 1/8(G_{35} - 2G_{55} + G_{75}) \quad (4)$$

2. INTERPOLATION FOR RED AND BLUE PLANE

Second order approximation is required for the green plane only. The human visual system is less sensitive to red and blue planes, so first-order approximation is adequate for the interpolation of red and blue planes. A first-order approximation of a function is a mathematically determined formula to fit multiple data points. It is a linear approximation, straight line with a slope: a polynomial of degree 1. Also the inclusion of higher order terms for the interpolation of red and blue plane will not improve its accuracy because red and blue pixels are greatly under sampled compared to green pixels. Linear and Bilinear interpolation are used for red and blue plane.

3. EDGE ORIENTATION CLASSIFIER AND WMF

In order to prevent interpolation across edge and to preserve sharp color edge, an edge orientation map is used as classifier to determine the filter weights for a weighted median filter. Here a weighted median filter or a linear combiner can be used as a classifier. A linear combiner will blur an edge. So a weighted median filter is used as the classifier because it preserve sharp color edges, produce minimal color artifacts and reduces blurring in the output image. For every pixel, an edge orientation map is produced using the CFA image input. An edge orientation map indicates the possible orientation of an edge for that pixel. For the pixel to be interpolated, the horizontal and vertical gradients are determined by the known neighboring pixels in the CFA input image. The direction in which the gradient is smaller is assumed to be the direction along the edge and the direction in which the gradient is larger is assumed to be the direction across the edge in the neighborhood of this pixel. The significance of classifier is important only if there is an edge in the CFA input.

3.1 Gradient Calculation

At a red/blue pixel, e.g.,B_{45},the vertical gradient and horizontal gradient are defined as

$$V = |G_{35} - G_{55}|; H = |G_{44} - G_{46}|$$

At a green pixel, e.g.,G_{44} , the vertical gradient and horizontal gradient are defined as

$$V = |G_{34} - G_{54}|; H = |G_{43} - G_{45}|$$

For example at B_{45}, the diagonal gradients are defined as

$$|R_{34} - R_{56}| \text{ and } |R_{36} - R_{54}|$$

A logical function is used to produce an edge orientation map for the whole color filter array image.

$$f(V < H) = \begin{cases} 1, & \text{if } V < H \\ 0, & \text{otherwise} \end{cases}$$

A "1" in the orientation map indicates that a possible edge along the vertical direction exists at that position while a "0" indicates a possible edge along the horizontal direction. To estimate the red/blue pixels at blue/red pixel locations, an edge orientation map for diagonal edges is used instead, due to the known red and blue pixel locations in the Bayer pattern.

3.2 Significance of classifier

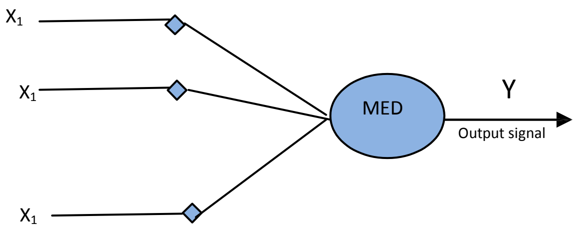

Fig 2: Weighted median filter.

For each pixel to be interpolated which was across the edge an edge orientation map is calculated and then it is passed through a 2-D standard median filter to remove any outliers. The success of median filters is based on two intrinsic properties: edge preservation and efficient noise attenuation with robustness against impulse noise. Edge preservation is essential in image processing due to the nature of visual perception. Based on the edge orientation map, the classifier weighted median filter produce an output. The edge orientation map output will be used to assign a higher weighting of the estimates for the orientation indicated by the map. This increases their probability to appear at the WMF output. Weighted median filter preserves sharp color edges and reduces blurring effect of the output image. Weighted median filter posses greater flexibility than median filters. The choice of non negative integer weights allows weighted median filters to posses certain degree of flexibility in preserving signal structures.

Weighted median filtering procedure can be stated as follows: sort the samples inside the filter window, duplicate each sample X, to the number of the corresponding weight W, and choose the median value from the new sequence. For the discrete-time continuous-valued input vector $X = [X_I, X_2, . . . , X_N]$, the output Y of the weighted median filter of span N associated with the integer weights: $W= [W_I, W_2, ..., W_N]$ is given by $Y = MED\ [W_I \diamond X_1, W_2 \diamond X_2, .. . , W_N \diamond X_N]$ where MED[.] denotes the median operation and $\diamond$denotes duplication. i.e., $K \diamond X = (X, ….X) \Rightarrow$ K times. For a vertical edge indicated in the edge orientation map, the output is given by $G = MEDIAN[G^L, G^R, 2 \diamond G^T, 2 \diamond G^B]$. For a horizontal edge indicated in the edge orientation map, the output is given by $G = MEDIAN[2 \diamond G^L, 2 \diamond G^R, G^T, G^B]$ where G^L, G^R, G^T, G^B are left, right, top and bottom green estimates.

5. PROPOSED DEMOSAICKING ALGORITHM

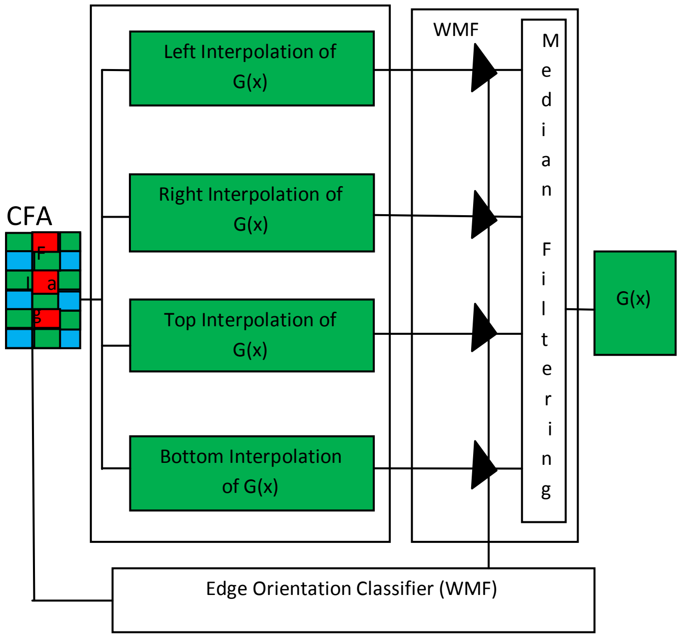

Fig 3: Block diagram of the proposed algorithm for the green plane.

This proposed method consists of two parts. In the first half, a second order interpolation algorithm, based on Taylor series is used to determine four estimates of the missing color value along four different directions. The four estimates will then be sent to the classifier i.e. weighted median filter to determine the green estimate output. The weights for classifier are determined by the edge orientation map according to the gradient estimation. Thus, the estimates obtained are more accurate than already existing methods due to the inclusion of higher-order terms. The spectral correlations refer to the fact there is a high correlation between the green and red/blue pixel values within a local neighborhood. Higher order approximation is required for the green plane only .For red and blue planes, first-order approximation is adequate.

6. RESULTS AND DISCUSSION

A non iterative demosaicking algorithm which is an application of Taylor series, based on directional interpolations is implemented to determine the missing color values to produce minimal color artifacts and is faithful to the original color even at sharp color edges. It outperforms other existing demosaicking algorithms for most types of images. This effective non iterative demosaicking algorithm preserves sharp color edges. Color edges are sharp boundaries between two distinct colors. The performance of this algorithm is compared to other four demosaicking algorithms. An important measure to analyze the various demosaicking methods such as PSNR is also implemented. The results from the experimentation can be found in Table I.

(a) (b) (c)

(d) (e) (f)

Fig 4: Images used for performance evaluation.

(a) (b) (c) (d) (e)

Fig 5: (a) Original Light House Image (b) Red Channel of Light House Image (c) Green Channel of Light House Image (d) Blue Channel of Light House Image (e) Demosaicked Light House Image.

Table I

Image Quality Performance Measures—PSNR DB

Image	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**
Bilinear	28.1	36.2	33.2	33.5	33.2	26.7
Freeman	33.1	42.3	38.1	40.2	34.5	34.2
Kimmel	31.3	38.4	33.4	36.8	30.0	29.3
Gunturk	40.1	43.1	39.6	41.8	33.8	37.6
M – HOI	37.8	40.2	38.5	39.1	40.7	34.2
S – HOI	**34.9**	**38.5**	**38.1**	**37.7**	**35.5**	**35.0**

7. CONCLUSION

A new interpolation technique based on Taylor series for CFA demosaicking with high accuracy is implemented for green plane. Using the new interpolation equations derived, four estimates from each opposite direction are determined. A weighted median filter of width four with weights determined by an edge orientation map is used to produce an output from the four estimates. The experimental results using various images of different characteristics demonstrated that high-order interpolation technique produce a demosaicked image with minimal artifacts and is faithful to the original color even at sharp color edges. There is no outright winner amongst them because it perform differently for various types of images. The high-order Interpolation method using the weighted median filter (WM-HOI) will produce better results for most types of images. Higher order approximation is required for the green plane only, and for the red and blue planes, first-order approximation is adequate. This is because the human visual system is less sensitive to red and blue. So first-order interpolation is sufficient. Experimental results confirm that the proposed method outperforms the existing state-of-the-art methods both visually and in terms of peak signal-to-noise ratio (PSNR), at a notably lower computational cost.

As further work, it could be further extended to include histogram equalization or a filter bank procedure so that the resulting demosaicked image can preserve much more sharp color edges with minimal color artifacts.

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