Combined Approach for Error Suppression in Demosaicing

1John Peter K, 2Nigitha D
1Head of the Department of IT, VINS Christian College of Engineering
2M.E Scholar (Software Engineering), VINS Christian College of Engineering

ABSTRACT
Conventional digital cameras have three sensors to capture the image which in turn costs high and requires more memory. In order to reduce the cost as well as the size, recent digital cameras are designed with single sensor to capture the image which samples only one color in each pixel. The missing color sample is reconstructed by interpolation and this method is called demosaicing. This paper uses a combined demosaicing approach to reduce the error in the edge region and improves the quality of the image by iteratively adaptive algorithm. In this paper, an initial interpolation is implemented by bilinear interpolation method. The missed green channel is reconstructed using color difference model. Successively, the red as well as the blue channels are reconstructed using hue model which reduces the error in the edge field. Meanwhile an iteratively adapted algorithm which duly incorporates edge sensing interpolation mechanism and luminance color difference model is used to improve the RGB channels. Finally, the red and blue channels are refined to improve the visual quality. Simulation results shows that the proposed algorithm is better than that of the existing algorithm in terms of visual quality and peak signal to noise ratio (PSNR).

Keywords: Interpolation, Demosaicing, Image enhancement, Image reconstruction

I. INTRODUCTION
With the development of information techniques, digital cameras have been widely used to capture images. Although some professional digital cameras use this structure, the cost of this structure is too high. To reduce the cost of the digital camera and the amount of memory to store the captured image, digital cameras are designed to use a CCD detector and a color filter array (CFA) to capture images. In the mosaic image, only one primary color is sampled in each pixel. Therefore, the missing color primaries must be reconstructed by interpolating the sampled color primaries of its adjacent pixels. The interpolation between color planes is known as demosaicing or CFA interpolation. The Bayer color filter array is a popular format for digital acquisition of color images.

A color image formation model was used to construct a demosaicing algorithm for image reconstruction. The model used the template matching technique and steerable inverse diffusion in color to achieve better perceptual results than those that are bounded by the sampling theoretical limit. An edge-directed interpolation algorithm for natural images was proposed. The algorithm firstly estimated local covariance coefficients from a low-resolution image and then used the covariance to adapt the interpolation at a higher resolution based on the geometric duality between the low-resolution covariance and the high-resolution covariance. An effective CFA interpolation (ECI) method was used to improve the image quality. The method for digital still cameras used a simple image model that correlates the R, G, and B channels. In existing, authors presented a directionally weighted color interpolation method to address the problem, where most demosaicing approaches often introduce false colors or blurred edges to areas with dense edges. In a model that characterizes a one-color per spatial position image as a coding into luminance and chrominance of the corresponding three colors per spatial position image was defined. The model gave new insights on the representation of single-color per spatial location images and enables controllable procedures to design demosaicing algorithms. In an iterative asymmetric, average interpolation was introduced to design the demosaicing method. Missing primary colors were estimated by an asymmetric average interpolation where less intensity variation is assumed to be of
stronger significance, before sharpness of an initial estimate is further improved by an iterative procedure. In this paper, a combined demosaicing approach that incorporates three image models is proposed to suppress the artifacts around edges for higher visual quality.

First, a preliminary interpolation is achieved by bilinear interpolation. The green channel is then updated using the color difference model. The proposed hue model that can reduce the distortion around edges is successively used to update red and blue channels. Finally, an iteratively adaptive algorithm using edge-sensing interpolation mechanism and luminance-color difference model is exploited to suppress artifacts in the edge region.

Finally, the red and blue channels are refined to improve the quality. The paper is further organized as follows.

Bilinear interpolation and three image models including color difference model, hue model, and luminance-color difference model are respectively presented in Section II. The proposed hybrid demosaicing scheme is described in Section III. Simulation results and conclusions are respectively described in Sections IV and V.

II. COMBINED APPROACH

A. Bilinear Interpolation

Bilinear interpolation is the simplest method for CFA application. This method determines the value of a missing pixel based on the weighted average of its adjacent pixels in the CFA image, the average value of the upper, lower, left, and right pixels is assigned to the interpolated G value at B7, while the average value of the two adjacent pixels is assigned to the interpolated B value at G6.

\[ G7' = \frac{G3 + G6 + G8 + G11}{4} \]  
\[ B6' = \frac{B5 + B7}{2} \]

The average of four adjacent diagonal pixel values is assigned to the interpolated R value at B7 and denoted by

\[ R7' = \frac{R2 + R4 + R10 + R12}{4} \]

Where R, G, and B are the red, green, and blue pixels captured from the CCD sensor and R, G, and B are the red, green, and blue pixels that are reconstructed by interpolation.

B. Color difference model

Because of the high correlation between red, green and blue signals of color images, the interpolation method for green signals can take advantage of red and blue information. The cocolor difference model is the correlation between green and chrominance signals. Two contrasts are adopted in the image model and defined as

\[ K_R = G - R \]  
\[ K_B = G - B \]

Where \( K_R \) is defined as green minus red and \( K_B \) as green minus blue for each pixel. The contrasts of \( K_R \) and \( K_B \) are quite flat over a small region for real-world images and this property is suitable for interpolation of the CFA image. The example of
the $K_R$ and $K_B$ images can be found in Fig. 3. The green channel of a color image is shown in Fig. 3a and the corresponding $K_R$, and $K_B$ images are shown in Fig. 3b and c, respectively. This property is suitable for interpolation of the CFA image. Based on this transformation, the interpolation error can be reduced and the visual quality of the restored image can be improved. The $G$ channel interpolation must be performed before the $R$, $B$ interpolations. This is because the method used to interpolate $R$, $B$ channels needs the interpolated value of $G$ channel. For this reason, we use this model to update the $G$ channel only and present the hue model to update $R$, $B$ channels for better performance. The hue model will be presented in the next subsection.

\[ HR = \frac{G - R}{G - B} \]  
\[ HB = \frac{G - B}{G - R} \]

For natural images, the contrasts of $HR$ and $HB$ are also quite flat over small region. In the proposed demosaicing scheme, we use this property to achieve color interpolation.

**D. Luminance color difference model**

Luminance information plays an important role while considering the visual quality of a color image. Three luminance-color difference planes or chrominance planes are defined as

\[ L_R = L - R \]  
\[ L_G = L - G \]  
\[ L_B = L - B \]

Where $L$ is the luminance plane. The three chrominance planes are generally smooth because the high-frequency contents of the luminance plane are highly correlated with that of each chrominance plane. Through exploiting this strong spatial smoothness in these luminance color difference planes, the luminance at the red and blue pixels are estimated by adaptively combining the neighbouring chrominance (luminance-color difference) values. By first reconstructing a satisfied luminance plane in the CFA demosaicing method, the corresponding performance will be better.

**III. THE PROPOSED ALGORITHM**

In this section, the basic idea behind the proposed algorithm is first introduced to clearly describe the logic behind the algorithm. To effectively obtain the initial interpolation results, the bilinear interpolation technique is adopted in the step 1. In the step 2, the green channel of the CFA image is then updated by applying the color difference model to the initial interpolation results. The red and blue channels of the CFA image are successively updated using the hue model in the step 3. In order to improve the visual quality of the updated image, an iteratively
3.1. Step 1: Initial interpolation
In this step, bilinear interpolation is applied to red, green, and blue channels of the CFA image to obtain
initial interpolation results. The objective of using the
initial interpolation results is to further update the
missing color primaries of each color channel such
that the inter-channel correlation can be exploited in
the following steps.

3.2. Step 2: Green channel updation
Since the green channel plays an important role to
represent the color image and the green channel is
sampled at a higher rate than the red and blue
channels in the Bayer color filter array, the green
component is updated first. By utilizing the initial
interpolation results of red and blue channels, we
use to update green channel in this step. To update
the green value at red and blue positions, the color
difference model is adopted. The green value at (x, y)
can be calculated as

\[ G(x, y) = R(x, y) + K_R(x, y), \quad (11) \]

where \( R(x, y) \) and \( K_R(x, y) \) are the red value and the
\( K_R \) value, respectively, at (x, y) in the original color
image. However, the actual \( K_R \) value cannot be
obtained in the CFA image. Using the preliminary
results from the step 1, the actual \( K_R \) value of a target
pixel is approximated by the estimated \( K_R \) values of
its neighboring pixels in this paper. We average four estimated \( K_R \) values of
the neighboring pixels to approximate the actual \( K_R \) at
(x, y). The estimated \( K_R \) values of the neighboring
pixels are calculated as

\[ K_R(p, q) = G(p, q) − R'(p, q) \text{ for } \]
\[ (p, q) \in \{(x + 1, y), (x − 1, y), (x, y − 1), (x, y + 1)\}, \]

The approximation of the actual \( K_R(x, y) \) is simply
calculated by

\[ K_R = \frac{K_R(x+1,y) + K_R(x-1,y) + K_R(x,y-1) + K_R(x,y+1)}{4} \quad (12) \]

The updated green value at red of position (x, y) is
therefore presented as

\[ G_2'(x, y) = B(x, y) + K_R'(x, y). \quad (13) \]

The updated green value at blue of position (x, y) is
presented as

\[ G_2'(x,y) = B(x,y) + K_R'(x,y)(14) \]

3.3. Step 3: Red and blue channel updation
In this step, the proposed hue model is used to
update red and blue channels. The process follows
the step 2. We transform the operation into hue
domain.

\[ R(x, y) = G(x, y) − HR(x, y)(G(x, y) − B(x, y)), \quad (15) \]

However, the actual HR value cannot be obtained in
the CFA image. Using the similar process that is
adopted in the previous step, the actual HR value can
be approximated. Using the preliminary results of
the step 1 and 2, the actual HR value of a target pixel
can be approximated by the estimated HR values of
its neighboring pixels.

The approximation of the actual \( H_R(x,y) \) is calculated by

\[ H_R(x,y) = \frac{HR_{x−1,y−1} + HR_{x−1,y+1} + HR_{x+1,y−1} + HR_{x+1,y+1}}{4} \quad (16) \]

The updated red value at blue of position (x, y) is
therefore presented as

\[ R'(x, y) = G_2'(x, y) − H''R(x, y)(G_2'(x, y) − B(x, y)) \quad (17) \]

The updated red values at green of position (x+1, y)
and (x, y-1) are presented as

\[ R'(x + 1, y) = G(x + 1, y) − H'R(x + 1, y) (G(x + 1, y) − B'(x + 1, y)) \quad (18) \]

\[ R'(x, y − 1) = G(x, y − 1) − H'R(x, y − 1) (G(x, y − 1) − B'(x, y − 1)) \quad (19) \]

Where

\[ HR'(x+1, y) = \frac{HR'(x+1, y−1) + HR'(x+1, y+1)}{2} \quad (20) \]

\[ HR'(x, y−1) = \frac{HR'(x−1, y−1) + HR'(x+1, y−1)}{2} \quad (21) \]

The updated blue value at green of position (x+1, y)
and (x, y-1) are presented as

\[ B'(x + 1, y) = G(x + 1, y) − H'B(x + 1, y) (G(x + 1, y) − B'(x + 1, y)) \quad (22) \]
The difference value between two resolution luminance plane \( L' \) and \( L'' \) is expressed as:

\[
\Delta V = |L'\text{full}(x + 1, y) - L'\text{full}(x - 1, y)|
\]

The improved luminance value at \( (x, y) \) is obtained using the Sobel operators \( R'(x, y) \) and \( G' \) as follows:

\[
R'(x, y) = L'\text{full}(x, y) - \alpha \cdot \sum_{m=1}^{2} |P_{x+1}^m - P_{x-1}^m|, \quad Z = R, G, B
\]

where \( \alpha \) is a convergence parameter. Usually, the value that is close to 1.0 is used to better suppress artifact noises and to achieve better visual quality of the demosaiced image. In our experiment, \( \alpha = 0.95 \) is adopted.
3.5. Step 5: Refinement of red and blue channels
The image is refined to improve the visual quality. So the red and blue channels are refined in the final step. The red as well as the blue channels are refined by

\[ Q(x, y) = G(x, y) - \frac{D(x - 1, y) + D(x, y - 1) + D(x, y + 1) + D(x + 1, y)}{4} \]  

(35)

Where

\[ G(x, y) = \begin{cases} 
R(x, y) + \text{median}(G - R) \\
B(x, y) + \text{median}(G - B) 
\end{cases} \]  

(36)

IV. EXPERIMENTAL RESULTS

In this section, the benchmark color images shown in are used in our experiments. In order to verify that the proposed combined demosaicing algorithm can utilize the proposed iteratively adaptive algorithm to suppress artifacts around edges. It is used to describe the artifacts occurring in the CFA interpolation process. Since the artifacts usually occur in the edge region, the proposed algorithm therefore utilizes an edge-sensing interpolation mechanism to suppress these visible artifacts. Meanwhile, the mechanism is incorporated with the luminance-color difference model where the luminance is accurately estimated to improve the visual quality of the reconstructed image. Finally, the refinement in the last step improves the visual quality of the image. To evaluate the performance, the demosaiced results of the proposed demosaicing method are compared with those of the existing demosaicing methods. In the simulations, the corresponding CFA images are obtained by sub-sampling each color channel of the color images. Finally, the red and the blue channels are refined to improve the accuracy of the PSNR value and the image. The performance in terms of PSNR of the restored images can be found in Table 1. It can be found that the proposed method outperforms others in terms of PSNR results.

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<tr>
<th>S.N</th>
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<th>Iteratively adaptive method</th>
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V. CONCLUSION

In this paper, a combined demosaicing scheme with better performance is proposed. The scheme incorporates the bilinear interpolation, the color difference model, and the hue model to successively update green, red, and blue channels of the CFA image, in which the hue model is successfully proposed to update the abrupt hue change of artifacts in the edge region of the demosaiced image. By further utilizing the proposed iteratively adaptive
algorithm, and the refinement of red and blue channels improves visual quality of the restored image by artifact suppression around edges. Simulation results show that the proposed algorithm can obtain higher PSNR and better visual quality compared with the existing demosaicing methods.

REFERENCES