CHAPTER 3

PROPOSED PERIODIC CFA DEMOSAICING TECHNIQUE

3.1 INTRODUCTION

Chapter 2 is discussed Literature review related to different interpolation domains such as Spatial and Frequency domain respectively. This chapter emphasis on proposed periodic CFA with demosaicing. In which the images undergoes demosaicing process yield good visual perception.

3.2 METHODOLOGY

3.2.1 Proposed demosaicing processes

For the perfect image reconstruction the main contribution for the proposed demasaiicing techniques are,

- To select the proper color filter array pattern to get duplicate copy of original color image channel pixel value.
- To design proposed edge preserve non-threshold interpolation algorithm and evaluate the performance of the interpolation technique.
- To analyze the existing technique with proposed algorithm with various performance measures.
• To analyze the need for the Post processing step to filter demosaicing noise.

### 3.2.2 Architecture system Block for Demosaicing Pipeline

Figure 3.1 shows the System Block Diagram for Demosaicing Process for single sensor camera image pipeline process. Input data set image is given to the CFA pattern and it will produce raw CFA filtered image based on the CFA pattern what we are applied. After interpolation update the color channels such as green, red and blue. Finally Hybrid Edge-Adaptive Median Demosaicing Artifact Filtering approach used to remove artifacts produced in demosaicing, give better PSNR value and Full color Enhanced Demosaiced Output Image.

![System Block Diagram for Demosaicing Process](image.png)

**Figure 3.1 System Block Diagram for Demosaicing Process**
3.2.3 Flow Model for Demosaicing Process

Figure 3.2 Flow Model for proposed demosaicing process
The proposed demosaicing process flow model is shown in Figure 3.2.

3.2.4 RGBYC Color Filter Array

The designing of sampling pattern plays a major role in camera image pipelining process. In conventional methods, there are two types of approaches that is periodic and non-periodic. The Bayer pattern is the one which is widely used image sensor. It has red, green and blue pixel surrounded by green pixel in vertical and horizontal direction respectively. This leads to cross-talk signals from green to blue and red pixel, so red and blue pixels are affected and similarly red and blue pixels are affected by cross-talk. However, cross talk reduces original signal for each of the blue, red and green pixel.

The accuracy of color acquisition device is increased by increasing the sampling of distinct colors. The different types of CFA arrangements are used commercially. In our new optimal proposed color filter array, we have added two additional color pixels between every two main pixel in the Bayer pattern. The additional color pixel values are obtained by adding the two red/blue green Bayer pattern colors [Cyan = Green + Blue; Yellow = Red + Green]. Cyan pixel is placed in centre of blue and green pixel and yellow pixel is placed in centre of red and green pixel.

The Figure 3.3 shows proposed RGBYC CFA pattern, it is have five different core colors such as Red, Green, Blue, Yellow and Cyan. To improve the accuracy and good visual clarity of refined image I proposed this CFA model of size 4x4.
To produce effective R, G and B channels that can utilize conventional tristimulus 3x3 matrices. If we combine channels to produce \( \bar{R} \), \( \bar{G} \) and \( \bar{B} \). It is expressed in the Equations (3.1), (3.2) and (3.3) as,

\[
\bar{R} = \frac{R + Y - G}{2} \quad (3.1)
\]
\[
\bar{G} = \frac{G + Y - R + C - B}{3} \quad (3.2)
\]
\[
\bar{B} = \frac{B + C - G}{2} \quad (3.3)
\]

The output signal received at each pixel response model is developed from the following Equation (3.4).

\[
C(\lambda) = k \cdot L(\lambda) \cdot X(\lambda) \cdot C D(\lambda) + N \quad (3.4)
\]
where the incident photo flux $L(\lambda)$, spectral reflectance $X(\lambda)$, spectral transmittance $CD(\lambda)$, pixel parameter constant $k$ (it includes pixel size and lens F-number) and $N$ is noise parameter (for simulation we include random noise as a short noise). The test images were developed from different CFA patterns of multispectral images generated using pixel response model equation (Equation 3.4).

### 3.2.5 Proposed CFA pattern

In addition to RGBYC pattern, we have proposed a new CFA model based on Bayer RGB pattern of size 4x4. It is shown in Figure 3.4. In a Human Visual perception system the scene/object color is recognized by cones. Cones-Located in the middle part of retina of Fovea, Sensitive to color. Rods are not involved in color vision of eye but sensitive to low levels of illumination.

Human Visual System Red, Blue and Green color reorganization having some weights based on that only color values are recognized. It’s measured that the sensitivity level of human eye reorganization to basic colors such as Red, Blue and Green are having weights 29.9%, 58.7% and 11.4% respectively. However in well known Bayer’s CFA pattern, the red color weight is assumed as 25%, green color weight is assumed as 50% and blue color weight is assumed as 25%. So Bayer’s Pattern CFA weight is not close to HVS actual weights.

Proposed systems CFA pattern is having color weights very near to actual HVS weights that is given as 25% for red channel, 62.5% for green channel and 12.5% for blue channel.
The individual mosaic CFA filter patterns are shown in Figure 3.5. At the time of demosaicing with the help of these filter values interpolate remaining pixel values individually.

Figure 3.5 Filter Patterns (a) Red Channel (b) Green Channel (c) Blue Channel
The mask used to filter the mosaic pattern channel is measured by multiplying input image with filter coefficient. Mask pattern pixel calculation is given as $R_{fm}$, $G_{fm}$ and $B_{fm}$ in Equation (3.5), (3.6) and (3.7) respectively.

$$R_{fm} = \frac{1}{16} \begin{bmatrix} 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \tag{3.5}$$

$$G_{fm} = \frac{9}{16} \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 1 \end{bmatrix} \tag{3.6}$$

$$B_{fm} = \frac{3}{16} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{3.7}$$

The response of the mosaiced image is obtained by multiplying equation 3.4 with matrix color filter mosaic it is given in equation 3.8.

$$\text{Im} = C(\lambda) \ast [R_{fm} \ G_{fm} \ B_{fm}] \tag{3.8}$$

### 3.2.6 Demosaicing of CFA Raw data

The process of extraction of missing colors from CFA samples is known as Interpolation. The output of interpolated CFA sample is Full-color Demosaiced image. In that output image, there is some noise (false colors or color artifacts) components may be added at the time of interpolation. This could be mitigated by using proper Post-Processing Step for the sake of getting a quality image, the output image at CFA Demosaicing process is
termed as Final Demosaiced image. The serial process of interpolation and post-processing step collectively termed as CFA Demosaicing. The Figure 3.6 depicts the CFA demosaicing process.

![Figure 3.6 CFA Demosaicing Process](image)

**3.2.6.1 Edge preserve non-threshold interpolation algorithm**

The proposed Edge Preserve Non-Threshold Interpolation algorithm first interpolates the green color samples. Successively the remaining color sample such Red and blue color samples are interpolated. The periodic CFA color pattern is less prone to the optical and electrical cross-talk demosaicing. However a periodic CFA pattern is prone to Moire Artifact, which may appear as repeating patterns.

**3.2.6.2 Initial directional color channel estimation**

Estimation of a directional color channel is used to avoid averaging of a non-correlated color channel this will improve demosaicing performance. Edge preservation is one of the important factors in our proposed demosaicing. The directional estimate of channels such as Green and Blue channels are initially calculated for Horizontal and Vertical directions it is represented as $G_H$ and $G_V$ then successively estimate for Red channel for Horizontal and Vertical directions. It is represented as $R_H$ and $R_V$ respectively. Similarly, for Blue channel estimate the color direction it is
represented as \( B_H \) and \( B_V \). The proposed CFA pattern to estimate directional color values is shown in Figure 3.7.

![Figure 3.7 Proposed CFA pattern for directional color values](image)

**Figure 3.7 Proposed CFA pattern for directional color values**

Estimation of the green channel in the horizontal direction for the pixel location \( G_{H_{is}}(i, j) \) is performed by considering pixel position of green channel such as \((i, j-2), (i, j+1), (i, j+2)\) and red channel pixel position \((i, j)\). The normalized value for the horizontal directional estimate is expressed in Equation 3.9.

\[
G_{H_{is}}(i, j) = \frac{G(i, j-2) + G(i, j+1)}{2} + \frac{2.R(i, j) + G(i, j+2)}{3} \quad (3.9)
\]

Similarly, for the vertical directional color value for green calculation is given in equation 3.10. It can be calculated by considering pixel
position for the green channel such as \((i-1, j), (i-2, j), (i+2, j)\) and red channel pixel position \((i, j)\) and considered normalized values.

\[
G_{V_{15}}(i, j) = \frac{G(i-1, j) + G(i-2, j)}{2} + \frac{2.R(i, j) + G(i+2, j)}{3} \quad (3.10)
\]

Next, for Red pixel directional values for horizontal and vertical direction is given in equation 3.11 and 3.12 respectively. For horizontal direction estimate raw CFA Blue pixel position \((i, j-1), (i, j+3)\), then interpolated Green pixel position \((i, j)\) are considered.

\[
B_{H_{15}}(i, j) = \frac{B(i, j-1) + B(i, j+3)}{2} + \frac{2.G(i, j) - G(i, j+2)}{2} \quad (3.11)
\]

\[
B_{V_{15}}(i, j) = \frac{B(i+1, j) + B(i-3, j)}{2} + \frac{2.G(i, j) - G(i-1, j)}{2} \quad (3.12)
\]

Where, H and V represents Horizontal and Vertical pixel for the location \((i, j)\). Similarly, the directional estimate for the red channel in Horizontal and vertical direction performed. It is expressed in Equation 3.13 and 3.14.

\[
R_{H_{21}}(i, j) = \frac{R(i-1, j-2) + R(i-1, j)}{2} + \frac{2.G(i-1, j) - G(i-1, j+1)}{2} \quad (3.13)
\]

\[
R_{V_{21}}(i, j) = R(i-1, j) + \frac{2.G(i-1, j) - G(i-2, j)}{2} \quad (3.14)
\]
3.2.6.3 Color difference estimation

Once G component is determined, the missing R and B values are calculated based on color difference interpolation method. The idea is that the color difference between R/B and G in a smooth region is thought to be constant. However, different neighboring locations of one center pixel have different correlations with it. The color difference for the green color is calculated from subtracted value from red channel, it is given in Equation (3.15) as,

\[
C_{H15}(i, j) = \begin{cases} 
G_{H15}(i, j) - R(i, j), & \text{if } G \text{ is interpolated} \\
G(i, j) - R_{H15}(i, j), & \text{if } R \text{ is interpolated}
\end{cases}
\]  

(3.15)

Color difference for the horizontal pixel location \(C_{H15}\) gives two channels such as Green interpolation and Red interpolation. For Green interpolation take the difference from Green in horizontal directional value with location \((i, j)\) with red raw pixel value with pixel coordinates \((i, j)\). If it is red interpolated take the difference from \(G(i, j)\) and red channel with horizontal direction pixel value with coordinate \((i, j)\).

Similarly, for vertical direction color difference can be estimated and it is given in equation 3.16.

\[
C_{V15}(i, j) = \begin{cases} 
G_{V15}(i, j) - R(i, j), & \text{if } G \text{ is interpolated} \\
G(i, j) - R_{V15}(i, j), & \text{if } R \text{ is interpolated}
\end{cases}
\]  

(3.16)

Color difference correlations are the important factor, to get a smooth color transition in entire region of an image.
The color difference between the successive or one after another pixel location are given for horizontal location. It is expressed in equation 3.17 as,

\[
DS_H(i, j) = \frac{2G(i, j + 1) - 2G(i, j - 1) - R(i, j + 2) - R(i, j - 2)}{4} 
\]  

(3.17)

For a vertical color difference between the successive or one after another pixel location are given for vertical location. It is expressed in equation 3.18 as,

\[
DS_v(i, j) = \frac{2G(i + 1, j) - 2G(i - 1, j) - R(i + 2, j) - R(i - 2, j)}{4} 
\]  

(3.18)

Multiscale color difference estimation gradients for the horizontal and vertical directions are estimated with red and green channels. The horizontal directional multiscale color difference is given in Equation 3.19 as,

\[
MG_{H15}(i, j) = \frac{G(i, j + 1) - G(i, j - 1)}{2} - \frac{R(i, j + 2) - R(i, j - 2)}{4} \
+ \frac{G(i, j + 3) - G(i, j - 3)}{2} - \frac{R(i, j + 4) - R(i, j - 4)}{4} 
\]  

(3.19)

The vertical directional multiscale color difference is given in equation 3.20 as,
\[ MG_{V15}(i, j) = \frac{G(i + 1, j) - G(i - 1, j)}{2} + \frac{R(i + 2, j) - R(i - 2, j)}{4} + \frac{G(i + 3, j) - G(i - 3, j)}{2} - \frac{R(i + 4, j) - R(i - 4, j)}{4} \]

\[ \text{(3.20)} \]

### 3.2.6.4 Green channel interpolation

Missing Green channel pixel information interpolated using this proposed approach. To perform the interpolation automatically undergone multiscale color difference equation. Horizontal and vertical directional green pixel use two-pixel location both direction from target pixel with Multiscale color difference expression. The Equation 3.21 expresses the green interpolation with Red pixel.

\[
G(i, j) = \begin{cases} 
C_{WH} & \frac{G(i + 1, j) - G(i, j - 1)}{2} - \frac{R(i, j + 2) - R(i, j - 2)}{4} \\
C_{WV} & \frac{G(i, j + 1) - G(i, j - 1)}{2} - \frac{R(i + 2, j) - R(i, j - 2)}{4} \\
& \frac{G(i + 3, j) - G(i - 3, j)}{2} - \frac{R(i + 4, j) - R(i - 4, j)}{4} \\
& \frac{G(i + 4, j) - G(i - 4, j)}{4} \\
\end{cases} \]

\[ \text{if } G_H > G_V \]

\[ \text{if } G_H < G_V \]

\[ \text{if } G_H = G_V \]

\[ \text{(3.21)} \]

Where, \( C_{WH} \) and \( C_{WV} \) are weight function for horizontal and vertical directions. Similarly for missing green pixel interpolated by available green and blue pixel location. It is given in Equation 3.22 as,
Interpolation of green pixel value estimated by using the Equations 3.21 or 3.22. It will check for three cases such as horizontal green pixel value greater vertical green pixel value, less than green pixel value and equal to the green pixel value.

3.2.6.5 Red and blue channel interpolation

For the interpolation of red and blue pixel values follow up the color rule and color difference approach. In color difference approach red and blue pixel values are arrange in form of color difference domain. The color difference values such as R-G and B-G were determined. To generate the full-color image value of the red and green pixel, add the Green value with color difference domain value. Red pixel interpolation expressed in Equation 3.23 as,
\[
\hat{R}(i, j) = \hat{G}(i, j) - \frac{CW_v^*(G_{i-1,j} - R_{i-1,j} + G_{i+1,j} - R_{i+1,j})}{2*(CW_v + CW_h)} - \frac{CW_h^*(G_{i,j-1} - R_{i,j-1} + G_{i,j+1} - R_{i,j+1})}{2*(CW_v + CW_h)} (3.23)
\]

For blue pixel interpolation using color difference approach is given in equation 3.24 as,

\[
\hat{B}(i, j) = \hat{G}(i, j) - \frac{CW_v^*(G_{i-1,j} - B_{i-1,j} + G_{i+1,j} - B_{i+1,j})}{2*(CW_v + CW_h)} - \frac{CW_h^*(G_{i,j-1} - B_{i,j-1} + G_{i,j+1} - B_{i,j+1})}{2*(CW_v + CW_h)} (3.24)
\]

The smooth full-color image can be obtained from the expressions 3.23 and 3.24. It gives good high-quality image when compared to independent color channel interpolation process.

3.2.6.6 Update green channel

After the basic initial interpolation is performed next step is to update the color value in its original target position. While updating the target pixel every surrounding neighbour pixel also to be considered. It is used to avoid edge crossing. The green channel update shown in Figure 3.8(a) and (b). Figure 3.8(a) shows the green channel input raw CFA pixel data, initially the target pixel locations B8, B9, B14, and R15 are to be updated. The updated green data for the target position such as G8, G9, G14 and G15 are shown in Figure 3.8 (b). The highlighted square portion indicates the green target pixels were updated.
3.3 RESULTS OF INTERPOLATION

The proposed algorithm was tested with Kodak dataset of 24 images of resolution 768x512 described in Xin Li et al. (2008) and McMaster dataset of 18 images of resolution 500x500 which is used in Xin Li et al. (2008) and Wang Guo-gang et al. (2012).

In Edge Preserve Non-Threshold Interpolation Algorithm includes the interpolation of Red, Green and Blue channels of pixel and generate full color image by combining all the color values. Figure 3.9 to 3.12 shows results of interpolation process which consists of Red, Green and Blue channel images and interpolated full-color image.
Figure 3.9  Interpolated Kodak image 1 (a) Input Kodak image set 1 (b) Individual color Red Green and Blue channel image (c) Output Full Color Image
Figure 3.10 Interpolated Kodak image 2
(a) Input Kodak image set 2
(b) Individual color Red Green and Blue channel image
(c) Output Full Color Image
Figure 3.11 Interpolated McMaster image
1(a) Input McMaster image set 1  (b) Individual color Red Green and Blue channel image
(c) Output Full Color Image
Figure 3.12 Interpolated McMaster image 2 (a) Input McMaster image set 2 (b) Individual color Red Green and Blue channel image (c) Output Full Color Image
Based on interpolation result, it is seen that the proposed algorithm can effectively demosaic the input image for the proposed CFA pattern.

3.4 SUMMARY

In this chapter, a novel interpolation technique is proposed in spatial domain using Edge Preserve Non-threshold Interpolation algorithm. From the results, it is observed that the interpolated images of Kodak data set and McMaster data set was as same as that of the input image, that is the proposed CFA pattern and demosaicing algorithm which provides better visual perception in terms of S-CIELab and Computational time complexity. The next chapter is extended to post-processing of demosaiced image and performance evaluation.