An Adoptive approach in Demosaicing True Color from Digital Camera having Bayer Color Filter

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Abstract-- Single sensor with Bayer pattern color filters are used to reduce size and cost of consumer digital cameras. These cameras use various demosaicing algorithms to construct the entire image with true colors from the acquired insufficient RGB (Red,Green and Blue) mosaics. In order to estimate original true colors, iterative demosaicing algorithms are being employed. These algorithms incur high cost in computing and process all the pixels irrespective of the content of the image. The computation expense of algorithm and the quality of image are directly proportional. However, it has been observed that for homogeneous region, the simple (non-iterative) and complicated (iterative) demosaicing algorithms yield result in same image quality. In this paper, homogeneous and heterogeneous regions of images are identified using neighboring color dependency matrices namely NRDM (Neighboring Red Dependency Matrix), NBDM (Neighboring Blue Dependency Matrix) and NGrDM (Neighboring Green Dependency Matrix). The color distribution of homogeneous, heterogeneous regions is evaluated from these dependency matrices and used to identify the type of selected region. The identified region type is considered for determining a demosaicing algorithm having less computation provides the same image quality. The simple, non-iterative demosaicing algorithms are employed in homogeneous regions and iterative algorithms are used in heterogeneous regions. The image quality metrics Mean Square Error (MSE) is used to evaluate the proposed adaptive method with the existing iterative algorithms. The reduction in MSE values shows the effectiveness of the proposed adaptive approach.

Keywords- Demosaicing, Color Dependency Matrix, Homogeneous & Heterogeneous regions

I. INTRODUCTION

The digital imaging systems are available in most of the consumer products. There is large demand to reduce complexity and cost of the imaging systems without compromising the resolution and color of the digital image. Several operations occur in the image processing pipeline after an image is being captured from a digital camera. Here we deal only with Color Filter Array (CFA) interpolation. The commonly used CFA sensor is Bayer array pattern. Demosaicing must be applied to CFA which reconstructs the full color interpolated image. Demosaicing is widely used for mobile phone imaging, digital photo authentication [2] and image authentication [3].

A. Demosaicing Algorithms

The process of reconstructing a entire color image from the Color Filter Array pattern is called demosaicing. The demosaicing algorithms are classified into Adaptive algorithms, Heuristic algorithms with filtering operations, Inter-channel correlation algorithms and Iterative algorithms. Adaptive algorithms concentrate on sharp features, edges and quality of an interpolated image. Examples of adaptive algorithms are adaptive demosaicing [4] proposed by Ramanath et.al, Adaptive Homogeneity Directed demosaicing [5] proposed by Parks et.al ,edge adaptive algorithm proposed by Hur et.al [6], CFA recovery using variable number of gradients[7]. False color suppression [8] and Freeman algorithm [13] uses median filtering [9] of chrominance components to suppress the achromatic edges. Other examples are Vector color filter array demosaicing [10], Mean removed classified vector quantization [11]. Inter-channel correlation algorithms use the correlation between the wavelet sub-bands coefficients in high frequency regions. Cok [12] and Kimmel [14] proposed an algorithm based on the assumption that color ratios within an image object is constant. Keren and Osadchy [15], used local map algorithm to incorporate smoothness in chroma space is proposed. Alternative projection by Guntark [16] is an inter-channel algorithm belonging to POCS (Projection onto Convex Sets). Iterative algorithms have high computational cost. Some iterative algorithms are proposed in [17,18].

All the above algorithms work on each and every pixel irrespective of the content of the image. Simple (non iterative) and complicated (iterative and adaptive) algorithms gives the same result in homogenous regions. Hence, a content based adaptive algorithm is proposed in this work to demosaic insufficient RGB mosaics. Here, the region of the image is represented either homogenous or heterogeneous; the non-iterative, iterative algorithms are used respectively to interpolate the homogenous and heterogeneous regions. The rest of the publication is explained as follows. Section two describes Bayer filter pattern and NCDM matrix. Section three deals with

NRDM, NGrDM and NBDM matrices, their notations and definitions along with system architecture. The experimental results are discussed in section four, followed by conclusion and future enhancements

II. BACKGROUND

A. Bayer Filter

The unique arrangement of RGB color filter array on a grid of photo-sensors is called Bayer filter mosaic [1]. This arrangement of color filters is used in camcorders, scanners and digital cameras for the purpose of creating color images. The filter pattern is 25% red, 50% green, and 25% blue. Each pixel is filtered to record only one of three colors. To obtain a full-color image, various demosaicing algorithms discussed above are used.

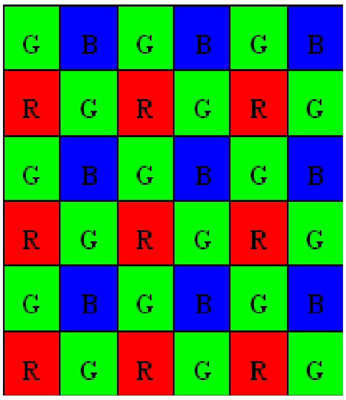

Figure 1. Bayer pattern of single sensor digital camera [1]

B. NCDM (Neighboring Color Dependency Matrix

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NCDM (Neighboring Color Dependency Matrix) was introduced by Jacquin & Smolarz [19] in 2008. Here the color area classification is performed by reducing the texture to 64 colors using "minimum variance quantization" algorithm. The texture is transferred in L1 norm color space. The construction of matrix depends on two parameters.-'a' & 'd', where a is the threshold of difference between two colors and d is the parameter fixing the size of the neighborhood. Here the 'a' value is fixed automatically by seeking the mean of the perceptual distances (PD) for all color couples. This mean is computed as below.

$$a = \frac{\sum_{u=0}^{N_h-1} \sum_{v=0, v\neq u}^{N_h-1} PD(u,v)\, f(u)}{N_h(N_h-1)}$$

where, N_h is the number of colors in an image and PD is the perceptual distances between two colors C1(l1,c1) and C2(l2,c2) calculated in RGB space as follows.

$$PD(C1,C2) = \sqrt{(R1-R2)^2 + (G1-G2)^2 + (B1-B2)^2}\ .$$

Hence NCDM denoted as Q is given by

$$Q_{d,a}(h,s) = \#\{(l,c) \mid C(l,c) = h \quad and \quad \#[i, j \in V_d \mid PD(C(l,c), C(i,j)) \le \alpha] = s\}$$

where C(l,c) is the color of the pixel in RGB, h denotes the color triplet, V_d is the set of neighbors in an n * n neighborhood and s is the random variable that represents the number of neighbors.

III. PROPOSED WORK

The approach presented in this paper for color interpolation is based on the dependence of color between the neighboring pixels. It is an extension to NCDM proposed by Jacquin and Smolarz [19] where the matrix has to be computed for 2^{24} colors (16,777,216 colors) which is difficult to compute and involves high computational cost. So, color reduction is performed using "minimum variance quantization" algorithm where the color palette is reduced to 64 colors. Hence the actual color palette is not maintained. In this paper, three matrices namely NRDM (Neighboring Red Dependency Matrix), NBDM (Neighboring Blue Dependency Matrix) and NGrDM

(Neighboring Green Dependency Matrix) are computed where the color dependency is estimated between a central pixel and its neighbors in a n * n neighborhood with d=1, 2, 3, etc and n=3, 5, 7, etc. In our approach the actual color palette of the image is maintained without color reduction and the image is segmented into homogenous and heterogeneous regions. Non-iterative algorithms (simple) are used for interpolating homogenous regions and iterative and adaptive algorithms are used for interpolating heterogeneous regions.

A. Notations used in NRDM, NBDM and NGrDM matrices

The notations used in NRDM, NBDM, NGrDM matrices are given below;

R(l,c) ,B(l,c) , G(l,c)	Random variable indicating Hue, Brightness and Saturation associated to the red, blue, green pixels with coordinates (l,c)
d	Parameter fixing the size of the neighborhood
V_d	Number of Neighbors of a pixel
ρ [(l1,c1),(l2,c2)]	Here ρ = max|l1-l2|,|c1-c2| is the distance between two pixels of coordinates (l1,c1) and (l2,c2)
DP	Perceptual Difference (Parameter fixing degree of proximity between colors of close pixels).Here the DP is calculated separately for R,G,B.
S	Random variable associated to the number of neighbors of a pixel.

The construction of the matrices depends on 2 parameters –'a' and 'd'. The parameter 'd' is the size of the neighborhood and parameter 'a' is the threshold of difference between two colors. The value of the parameter 'a' depends on the analyzed image. Here aR, aG, aB are computed separately. The aR is given by mean of $\sqrt{(R1-R2)^2}$ for the whole image. Similarly aG and aB are calculated as mean of $\sqrt{(B1-B2)^2}$ and mean of $\sqrt{(G1-G2)^2}$ .The dimensions of the matrix are [values of R/G/B from 0-255 * number of neighbors from 0-8].

B. Definition of the matrices

The dependency matrices NRDM, NGrDM and NBDM are defined as follows.

NRDM (Neighboring Red Dependency Matrix) is defined in the equation 1 as follows.

$$Q_{d,a}(h,s) = \#\{(l,c) \mid C(l,c) = h \quad and \quad \#[i,j \in V_d \mid PD(C(l,c),C(i,j)) \leq \alpha] = s\}$$

$$NRDM_{(d,aR)}(r,s) = \{(l,c) \mid R(l,c) = r \& \#[(i,j) \in V_d \mid R(l,c) - R(i,j) \mid <= aR] = s\} --> (1)$$

where NRDM is a matrix of size N_R * (N_d+1) and NRDM(d,aR)(r,s) is the number of pixels in an image with red color that have exactly 's' neighbors with red color in the interval [r-aR,r+aR].

NGrDM (Neighboring Green Dependency Matrix) is defined in the equation 2 as follows.

$$NGrDM_{(d,aG)}(r,s) = \{(l,c) \mid G(l,c) = g \& \#[(i,j) \in V_d \mid G(l,c) - G(i,j) \mid <= aG] = s\} --> (2)$$

where NGrDM is a matrix of size N_{Gr} * (N_d+1) and NGrDM(d,aG) (r,s) is the number of pixels in an image with green color that have exactly 's' neighbors with green color in the interval [g-aG,g+aG].

Similarly NBDM (Neighboring Blue Dependency Matrix) is defined in the equation 3 as follows:

$$NBDM_{(d,aB)}(r,s) = \{(l,c) \mid B(l,c) = b \& \#[(i,j) \in V_d \mid B(l,c) - B(i,j) \mid <= aB] = s\} --> (3)$$

where NBDM is a matrix of size N_B * (N_d+1) and NBDM(d,aB)(r,s) is the number of pixels in an image with blue color that have exactly 's' neighbors with blue color in the interval [b-aB, b+aB].

C. Separation method for Homogenous and Heterogeneous region

Each image consists of a set of approximately homogenous and heterogeneous color texture regions. Here, we compute hom(r), het(r), hom(g), het(g), hom(b) and het(b) from the dependency matrices NRDM ,NBDM and NGrDM. Since these matrices are computed here in 3*3 neighborhood with one central pixel with eight neighbours, the first column(0 neighbor) of these matrices characterizes the most heterogeneous regions and the last column(8 neighbors) of these matrices characterizes the most homogenous regions. A pixel is identified as homogenous/heterogeneous based on the following rule. If the reconstructed pixel's R, G, B values have s>=4, then the pixel is identified as homogenous. If any one of (R,G) or (R,B) or (B,G) values have s<=4,then the pixel is identified as homogenous. The pixel is identified as heterogeneous if (R, G,B) or (R,G) or (R,B) or (B,G) have (s > 4).This rule is termed as 'separation rule'.

D. System Architecture

The process taking place in identifying the heterogeneous regions through computation of dependency matrices and separation of image into homogeneous and heterogeneous regions is shown in the figure 2.

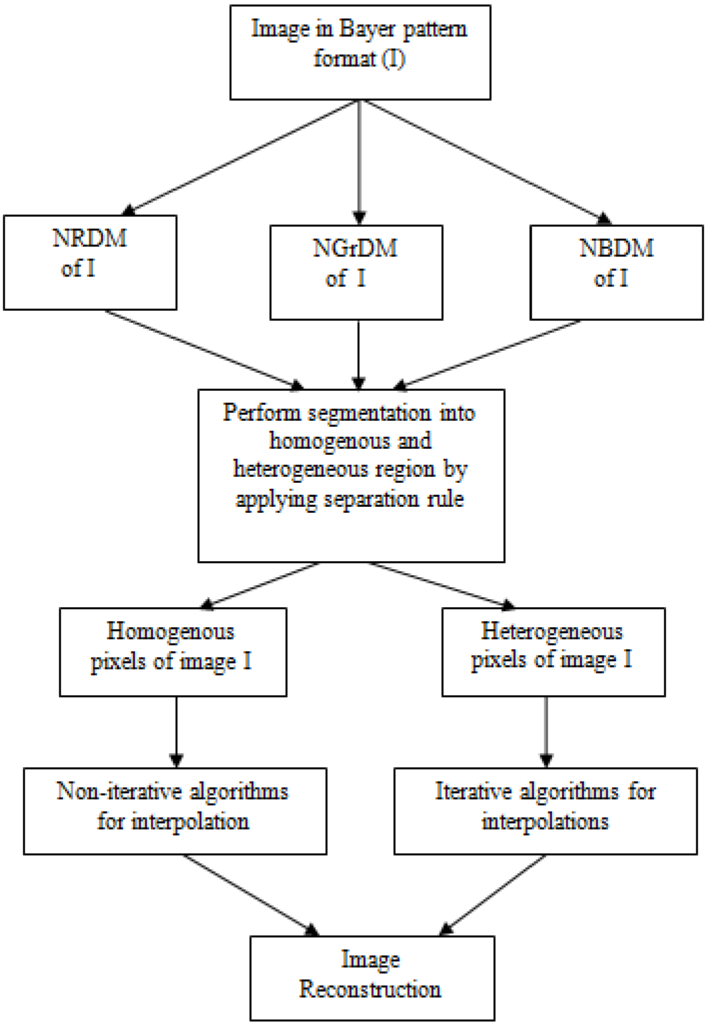

Figure 2. Architecture diagram showing the steps involved

The steps involved in the entire process are summarized as follows:

- Step 1: The input image in Bayer pattern format is interpolated using non iterative algorithm to retrieve R,G,B values for all image pixels.
- Step 2: Calculate the dependency matrices NRDM, NGrDM, NBDM for reconstructed values which gives the information of distribution of colors R, G, B. The coefficients of the matrices are arranged such that most heterogeneous color value (0 neighbor) are present on the left side of the matrix and most homogeneous color value (8 neighbor) are present on the right side of the matrix .
- Step 3:Now the dependency matrices have 256 rows for R,G,B values from 0-255 and 9 columns(0-8 neighbors) in a n*n neighborhood with d=1,2,3,etc where n=3,5,7,etc.
- Step 4: Perform the homogenous and heterogeneous separation of the image using NRDM, NGrDM, NBDM matrices using the separation rule given in sec 3.3
- Step 5:The heterogeneous regions consisting of edges which are improperly reconstructed are extracted separately and iterative demosaicing algorithms are used to interpolate them and R,G,B values are updated .A systematic survey on Image demosaicing [20] made by Li, Guntark and Zhang proved that NEDI(New edge directed Interpolation) [21],an intra-channel algorithm which exploits spatial and spectral correlation fused with LT(Lu and Tan) [22], an inter-channel showed impressive performance for both Kodax and IMAX datasets. Hence NEDI algorithm coupled with LT can be used for interpolating heterogeneous regions.
- Step 6: Hence the heterogeneous regions are interpolated using iterative, adaptive algorithms. The final full color reconstructed image consists of closer R,G,B values to the original baseline image.
- Step 7: The percentage of homogenous and heterogeneous regions is calculated which serves to be of important use in Content Based Image Retrieval(CBIR).

Further, the pseudocode for calculating neighbourhood dependency values is given below.

function calculateneighbour(reconstructed matrix[rows][columns])

returns dependency values

Inputs: reconstructed full color interpolated matrix that contains R,G,B values of all pixels, aR, aG, Bb(threshold of difference between R,G,B values)

Local variables: height=0,width=0,count=0,op=0,lower threshold s=0,upper threshold b=0

for each row!=0 and col!=0 and row!=h-1 and col!=w-1 **do**

S=matrix[][]-a and b=matrix[][]+a

count=0

for each (n*n -1) neighboring pixel with 1 one central pixel **do**

count=count+1 (if matrix[i][j]>=s and matrix[i][j]<=b)

end for

display op[matrix[r][c]] which contains dependency values

end for

Three output matrices which contains dependency values of R,G,B

end function

IV. EXPERIMENTAL RESULTS

The image obtained from single sensor in Bayer pattern format is initially interpolated using non-iterative algorithm to obtain the R, G, B values. Here edge directed with constant hue based is used for initial interpolation. Then aR, aG, aB are calculated as in section 3 for computing the dependency matrices. The matrices are framed such that the coefficients of the matrix are arranged from most heterogeneous region to most homogenous region. Then artifacts in the heterogeneous region are identified and interpolated by iterative algorithm and values are updated in the initially reconstructed image. Some of the images obtained from CMU VASC image database are tested experimentally. MSE values before and after segmentation are shown in Table I. The percentage of homogeneity and heterogeneity in an image is also calculated.

TABLE I. PERCENTAGE OF HOMOGENEITY AND HETEROGENITY

Images (CMU VASC database)	**Reconstructed MSE values with Edge directed and constant hue based**	**Reconstructed MSE values with Kimmel after segmentation**	**Percentage of homogeneity & heterogeneity**	
			Homogenous	***Heterogeneous***
Image 1	41.56	18.22	66.34	33.66
Image 2	38.90	21.23	71.36	28.64
Image 3	33.44	15.56	69.45	30.55

V. CONCLUSION AND FUTURE ENHANCEMENTS

This paper explains the use of neighbouring dependency matrices applied in demosaicing process. Here image is segmented into homogenous and heterogeneous regions for images captured from single sensor cameras by maintaining the actual color palette without performing color reduction. All the demosaicing algorithms work on each and every pixel irrespective of the content of the image. Simple (non iterative) and complicated (iterative and adaptive) algorithms gives the same result in homogenous regions. Hence image is segmented into homogenous and heterogeneous regions, non iterative algorithms (simple) are used for interpolating homogenous regions and iterative and adaptive algorithms are used for interpolating heterogeneous regions. Image artifacts identified in the heterogeneous regions are identified and corrected and the values are updated in the reconstructed image. Edge directed with constant hue based is used for initial interpolation and Kimmel algorithm is used for interpolating heterogeneous regions. This method can also be examined by using other non-iterative and adaptive algorithms for better results. The exploitation of these dependency matrices can provide information on the color images such as the quantity of homogenous and heterogeneous areas along with their localization and the dominant colors present in the image. Hence it is useful in CBIR (Content Based Image Retrieval) systems.

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