Efficiency Comparison of Multi Scale Gradients Based Interpolation Using Patterns

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Abstract: Most of the current digital cameras use single sensor covered with a colour filter array(CFA). 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.
In this paper, A directional approach to CFA interpolation that makes use of multiscale color gradients. The relationship between color gradient on different scales is used to generate signals in vertical and horizontal directions. The method is easy to implement since it does not make any hard decision, noniterative and threshold free. The developed method is applied to Bayer and Lukac pattern with great results which shows that the relationship between gradients at different scales can be a very effective feature to optimally combine directional estimates. Result can be used to compare efficiency of both pattern by using PSNR and MSE values.

IndexTerms: Color Filter Array(CFA)interpolation,demosaicing, directional interpolation, multiscale color gradients.

I. Introduction

Digital cameras have become more and more popular in consumer electronics market. In order to economize the hardware cost, instead of using three sensors, most digital cameras capture a color image with a signal sensor imaging pipeline based on the well-known Bayer CFA ,where each pixel in the captured image has only one measured. In order to recover the full color image from the input mosaic image, the demosaicing process is used to estimate the other two color channels for each pixel. 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 CFA pattern layout plays an important role in the design of a CFA interpolation algorithm. Many different CFA patterns have been proposed over the years. While some of these are comprised of pure RGB channels, like Bayer and Lukac patterns shown in Fig. 1 [1], [2], others feature linear combinations of RGB channels [3],[4].

The aim of a demosaicing algorithm is to reconstruct a full color image (i.e. a full set of color triples) from the spatially under sampled colour channel output from the CFA. The algorithm should have different advantages: such as it's avoidance of the introduction of false color artifacts, such as chromatic aliases, zippering (abrupt unnatural changes of intensity over a number of

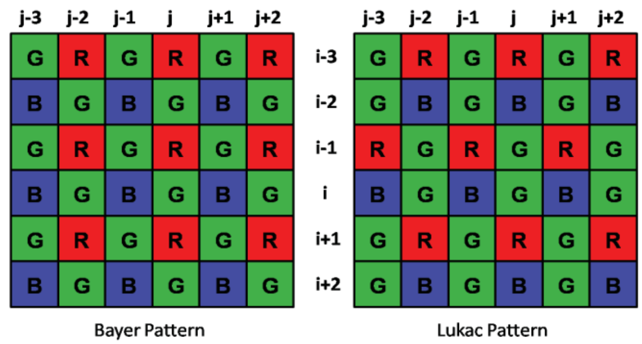

Fig. 1. Bayer and Lukac mosaic patterns

complexity for fast processing or efficient in-camera hardware implementation, amenability to analysis for accurate noise reduction.

The simplest way to address the demosaicing problem would be to treat each color channel seperately and interpolate missing samples using a spatially invariant method such as bilinear or bicubic interpolation. However, such a solution would lead to false color artifacts wherever there is a sudden color change. 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. So our proposed prediction algorithm provides a solution to the mentioned problem.

The main features of our algorithm is that it's applied to Bayer and Lukac pattern with great results which shows that the relationship between gradients at different scales can be a very effective feature to optimally combine directional estimates.

The rest of the paper is organized as follows. Section II survey related work Section III first gives the background of the proposed algorithm and then describes it in detail. Section and Section IV concludes the paper.

II. RELATED WORK

Demosaicing is an important part of the image processing in digital cameras. The failure of the employed demosaicing algorithm can degrade the overall image quality. So it has been an active research area for many years. Although there has been recent efforts to introduce generalized demosaicing algorithms, most demosaicing solutions in the literature are developed for the Bayer pattern[1]. The quality can be improved by applying the interpolation over color differences to take advantage of the correlation between the color channels[1]. However, the lack of spatial adaptiveness would still limit the interpolation performance.

R. Lukac and K.N. Plataniotis [2] used a normalized color-ratio model suitable for color filter array (CFA) interpolation. The first solution utilizes linear shifts to alleviate effects of edge variations in the interpolator's input. The second solution take advantages of both the linear scaling and shifting operations to normalize the color-ratio variations in the interpolator's input. Xin Li[3] used a fast and high-performance iterative algorithm for color filter array (CFA) demosaicing. The major contributions of this work include a new iterative demosaicing algorithm in the color difference domain and second one is a spatially adaptive stopping criterion for suppressing color misregistration and zipper artifacts in the demosaiced images. Ibrahim Pekkucuksen, Yucel Altunbasak[4] used a simple edge strength filter to interpolate the missing color values. The solution outperforms other available algorithms for the Lukac pattern in terms of both objective and subjective comparison.

Daniele Menon, Stefano Andriani, and Giancarlo Calvagno[5] used novel approach to demosaicing based on directional filtering and a posteriori decision. A refining step is included to further improve the resulting reconstructed image. Wenmiao Lu and Yap-Peng Tan[6] introduced a new CFA demosaicking method that consists of two successive steps: an interpolation step that fills in missing color values in a progressive fashion by exploiting the spectral and spatial correlations among neighboring pixels, and a post-processing step that incorporates spectral correlation with median filtering of inter-channel differences to suppress demosaicking artifacts.C.Naga raju, K.Subba reddy and C.Suneetha[7] proposes a method of CFA interpolation that combines information from the green image with the subsampled red and blue images to attack these problems. Kuo-Liang Chung,Wei-jen Yang,Wen-Ming Yan and Chung-chou Wang[8] proposed a method which does not use demosaicing processing,this first propose a new approach to extract more accurate gradient/edge information on mosaic images directl,.Next,based on spectural –spatial correlation. Henrique S. Malvar, Li-wei He, and Ross Cutler[9] presented a new demosaicing method for color interpolation of images captured from a single CCD using a Bayer color filter array. Nai-Xiang Lian, Lanlan Chang, Yap-Peng Tan and Vitali Zagorodnov[10] introduced a new approach which discussed two important observations for preserving high-frequency information in CFA demosaicking.

All the current approaches deal with demosaicing based on Bayer pattern.In the proposed system demosaicing based on Bayer and other RGB pattern (eg.Lukac pattern) and Compare the performance in both patterns.Efficiency of each one to be find out. Here A directional CFA interpolation method that is based on multiscale color gradients[1]. The developed method is applied to Bayer and Lukac patterns with great results which shows that the relationship between gradients at different scales can be a very effective feature to optimally combine directional estimates. This method the horizontal and vertical color difference estimates are blended based on the ratio of the total absolute values of vertical and horizontal color difference gradients over a local window.

II. PROPOSED ALGORITHM

A. Algorithm Background

The first step of the algorithm is to get initial directional color channel estimates.In this method, the horizontal and vertical color difference estimates are blended based on the ratio of the total absolute values of vertical and horizontal color difference gradients over a local window.

For red&green rows and columns in the input mosaic image Fig. 1,the directional estimates for the missing red and green pixel values are:

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

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

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

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

where H and V denote horizontal and vertical directions and (i, j) is the pixel location. For every pixel coordinate, a true color channel value and two directional estimates present. By taking their difference and get the directional color difference estimate:

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

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

The absolute color difference gradients at pixel coordinates (i, j) are given by:

$$D^H(i,j) = |\tilde{\Delta}^H(i,j-1) - \tilde{\Delta}^H(i,j+1)|$$
$$D^V(i,j) = |\tilde{\Delta}^V(i-1,j) - \tilde{\Delta}^V(i+1,j)|$$

The color difference gradients calculated above are used to find weights for each direction. The horizontal color difference gradient equation above can be written in terms of red and green pixel values as follows:

$$\begin{aligned} D^H(i,j) &= |(G(i,j-1) - \tilde{R}^H(i,j-1)) - (G(i,j+1) - \tilde{R}^H(i,j+1))| \\ &= \left| \left(\frac{2.G(i,j-1)+G(i,j-3)+G(i,j+1)}{4} - \frac{R(i,j-2)+R(i,j)}{2} \right) - \left(\frac{2.G(i,j+1)+G(i,j-1)+G(i,j+3)}{4} - \frac{R(i,j)+R(i,j+2)}{2} \right) \right|. \end{aligned} \quad (4)$$

We observe that there are $R(i, j)$ terms present and they cancel out each other. Rearranging with respect to different color channels leaves us with:

$$D^H(i,j) = \left| \frac{R(i,j+2)-R(i,j-2)}{2} - \frac{(G(i,j+3)+G(i,j+1))-(G(i,j-3)+G(i,j-1))}{4} \right|.$$

There are two important observations. First, 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 as illustrated in the top portion of Figure 3. Our second and more important observation is that, we can do these same operations at half the scale:

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

where $D_h(i,j)$ denotes the horizontal estimation at half the scale. We take the difference between the available color channel values one pixel (instead of two pixels) away from the target pixel, we do the same operation in terms of the other channel by using its closest samples, and then we take the difference between these two. At this scale, the $R(i,j)$ terms cancel each other out and we are left with:

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

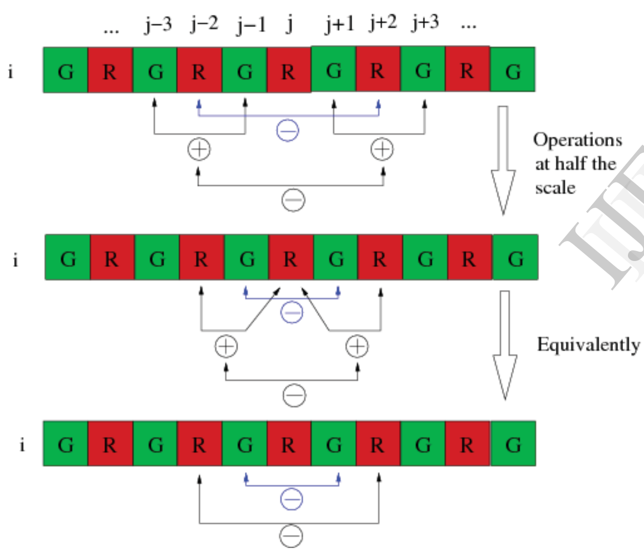

Fig. 3. Relationship between the color difference gradients equation and the multiscale gradients equation

The final multiscale gradients equations for red&green rows and columns can be given as follows:

$$D^h(i,j)=\left|\frac{G(i,j+1)-G(i,j-1)}{2} - \frac{R(i,j+2)-R(i,j-2)}{N_1} + \frac{G(i,j+3)-G(i,j-3)}{N_2} - \frac{R(i,j+4)-R(i,j-4)}{N_3} + \cdots\right|$$

$$D^v(i,j)=\left|\frac{G(i+1,j)-G(i-1,j)}{2} - \frac{R(i+2,j)-R(i-2,j)}{N_1} + \frac{G(i+3,j)-G(i-3,j)}{N_2} - \frac{R(i+4,j)-R(i-4,j)}{N_3} + \cdots\right|,$$

where the Ni terms are the normalizers. The equations are similar for blue&green rows and columns. Although Bayer mosaic pattern is a special case, this algorithm can be applied to other mosaic patterns with some modifications. This paper the Lukac mosaic pattern proposed in [1]. An inspection on the Lukac mosaic pattern reveals that it is possible to take gradients in three directions as opposed to four on the Bayer pattern. While we still have the horizontal component, the vertical one is gone and the diagonal components lean more towards the vertical direction. Based on this observation, some changes in equations needed to apply the Lukac patterns and get great results which shows that the relationship between gradients at different scales can be a very effective feature to optimally combine directional estimates.

B. Initial Green Channel Interpolation

Algorithm starts with interpolating the green channel. After updating the initial green channel interpolation results in one pass, the red and blue channels are filled in using the constant color difference assumption.

The ratio between the vertical and horizontal multiscale gradients results over a local window is employed at every stage. For initial green channel interpolation, we have directional color difference estimates around every green pixel to be interpolated and combine them adaptively:

$$\hat{\Delta}_{g,r}(i,j) = [w_V.\mathbf{f}.\tilde{\Delta}^V_{g,r}(i-1:i+1,j) + w_H.\tilde{\Delta}^H_{g,r}(i,j-1:j+1).\mathbf{f}']/w_C$$
$$w_C = w_V + w_H$$
$$\mathbf{f} = [1/4\ \ 2/4\ \ 1/4].$$

For a local window size of 5 by 5, the weight for each direction is calculated as follows:

$$w_V = 1/\left(\sum_{k=i-2}^{i+2}\sum_{l=j-2}^{j+2} D^v(k,l)\right)^2$$
$$w_H = 1/\left(\sum_{k=i-2}^{i+2}\sum_{l=j-2}^{j+2} D^h(k,l)\right)^2.$$

The division operation can be avoided by defining the weights as the denominators and exchanging them (The ratio of $1/a$ to $1/b$ is equal to the ratio of b to a provided that both are nonzero).

C. Green Channel Update

After the directional color difference estimates are combined as explained in the previous section, we can directly calculate the green channel and move onto completing the other channels. However, it is possible to improve the green channel results by updating the initial color difference estimates. We consider the closest four neighbors to the target pixel with each one having its own weight

$$\tilde{\Delta}_{g,r}(i,j) = \hat{\Delta}_{g,r}(i,j).(1-w) + [w_N.\hat{\Delta}_{g,r}(i-2,j) + w_S.\hat{\Delta}_{g,r}(i+2,j) + w_E.\hat{\Delta}_{g,r}(i,j-2) + w_W.\hat{\Delta}_{g,r}(i,j+2)] .w/w_T$$
$$w_T = w_N + w_S + w_E + w_W. \quad (11)$$

Again, the weights *(wN,wS,wE,wW)* are calculated by finding the total multiscale color gradients over a local window.For a 3 by 5 window for horizontal and a 5 by 3 window for vertical components, the weight calculations can be given as follows

$$w_N = 1/\left(\sum_{k=i-4}^{i}\sum_{l=j-1}^{j+1} D^v(k,l)\right)^2$$
$$w_S = 1/\left(\sum_{k=i}^{i+4}\sum_{l=j-1}^{j+1} D^v(k,l)\right)^2$$
$$w_W = 1/\left(\sum_{k=i-1}^{i+1}\sum_{l=j-4}^{j} D^h(k,l)\right)^2$$
$$w_E = 1/\left(\sum_{k=i-1}^{i+1}\sum_{l=j}^{j+4} D^h(k,l)\right)^2.$$

Once the color difference estimate is finalized, we add it to the available target pixel to obtain the estimated green channel value:

$$\tilde{G}(i,j) = R(i,j) + \bar{\Delta}_{g,r}(i,j)$$
$$\tilde{G}(i,j) = B(i,j) + \bar{\Delta}_{g,b}(i,j).$$

D. Red and Blue Channel Interpolation

For red and blue channel interpolation, we first complete the missing diagonal samples i.e. red pixel values at blue locations and blue pixel values at red locations. These pixels are interpolated using the 7 by 7 filter.

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

$$\tilde{R}_{i,j} = \tilde{G}_{i,j} - \bar{\Delta}_{g,r}(i-3:i+3, j-3:j+3) \otimes p_{rb}$$
$$\tilde{B}_{i,j} = \tilde{G}_{i,j} - \bar{\Delta}_{g,b}(i-3:i+3, j-3:j+3) \otimes p_{rb},$$

where $\otimes$ denotes element-wise matrix multiplication and subsequent summation.The red and blue pixels at green locations are interpolated adaptively. In order to avoid repetitive weight calculations, we reuse the directional weights (w_H, w_V). 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:

$$\tilde{R}(i,j) = G(i,j)$$
$$-\frac{w_V.(\tilde{G}(i-1,j)-R(i-1,j)+\tilde{G}(i+1,j)-R(i+1,j))}{2.(w_V+w_H)}$$
$$-\frac{w_H.(\tilde{G}(i,j-1)-\tilde{R}(i,j-1)+\tilde{G}(i,j+1)-\tilde{R}(i,j+1))}{2.(w_V+w_H)}$$
$$\tilde{B}(i,j) = G(i,j)$$
$$-\frac{w_V.(\tilde{G}(i-1,j)-\tilde{B}(i-1,j)+\tilde{G}(i+1,j)-\tilde{B}(i+1,j))}{2.(w_V+w_H)}$$
$$-\frac{w_H.(\tilde{G}(i,j-1)-B(i,j-1)+\tilde{G}(i,j+1)-B(i,j+1))}{2.(w_V+w_H)}.$$

The equations for the blue vertical neighbor case are similar. With the completion of red and blue pixel values at green coordinates, we obtain the full color image.

E. Application to the Lukac Pattern

Although designed for the Bayer mosaic pattern, the proposed method can be modified to be applied to other mosaic patterns. However, such an application may not be feasible for all mosaic patterns because of the restrictions dictated by the directional nature of our approach. When the modification is feasible, an important question would be whether the changes needed to comply with the new pattern layout lead to a significant performance loss or not. To find out if we can outperform other available solutions on a different pattern layout, we modified the proposed algorithm for the Lukac pattern. Lukac mosaic pattern is similar to Bayer pattern in the sense that it consists of pure RGB components. When we shift every other row in a Bayer pattern by one pixel to either side, we obtain the Lukac pattern. Hence, the horizontal relationship between the pixels is still the same, but the vertical arrangement is significantly altered. As a result of this, it is not possible to take immediate vertical gradients anymore. However, we observe that we can take vertical gradients when we double the scale. So we modified our vertical multiscale gradients equation accordingly:

$$D^v(i,j) = \left| \frac{G(i+2,j)-G(i-2,j)}{M_0} - \frac{R(i+4,j)-R(i-4,j)}{M_1} + \frac{G(i+6,j)-G(i-6,j)}{M_2} - \frac{R(i+8,j)-R(i-8,j)}{M_3} + \cdots \right|,$$

where the M_i terms are the normalizers The layout of the Lukac pattern also necessitates a change in vertical color difference estimation. Since all the required channel values are not available in the same column, we estimate the missing values by taking simple average using samples from adjacent columns, shown at the bottom of the previous page. Another problem we faced with the Lukac pattern was the mismatch between vertical and horizontal color difference estimates at green channel coordinates. Namely, the calculated vertical and horizontal color differences at these locations belong to different color pairs. That is why we bring the needed vertical color difference estimate from the closest available resource:

$$\tilde{R}^V(i,j) = \frac{\frac{R(i-1,j-1)+R(i-1,j+1)}{2} + R(i+1,j)}{2} + \frac{2.G(i,j) - \frac{G(i-2,j-1)+G(i-2,j+1)}{2} - \frac{G(i+2,j-1)+G(i+2,j+1)}{2}}{4}$$
$$\tilde{G}^V(i-1,j-1) = \frac{G(i-2,j-1) + \frac{G(i,j-2)+G(i,j)}{2}}{2} + \frac{2.R(i-1,j-1) - \frac{R(i-3,j-2)+R(i-3,j)}{2} - \frac{R(i+1,j-2)+R(i+1,j)}{2}}{4}.$$

$$\bar{\Delta}^V_{g,b}(i,j) = G(i-1,j) - \tilde{B}^V(i-1,j)$$
$$\bar{\Delta}^V_{g,r}(i-1,j) = G(i,j) - \tilde{R}^V(i,j).$$

Also, the combined color difference estimate equations are modified to bring the neighboring vertical estimates from two pixels away instead of one:

$$\begin{aligned}\hat{\Delta}_{g,r}(i-1,j-1) &= \left[w_V \mathbf{f}_v . \bar{\Delta}^V_{g,r}(i-3:i+1,j) + w_H . \bar{\Delta}^H_{g,r}(i-1,j-2:j) \mathbf{f}_h^T\right]/w_C \\ w_C &= w_V + w_H \\ \mathbf{f}_h &= [1/4\ 2/4\ 1/4] \\ \mathbf{f}_v &= [1/4\ 0\ 2/4\ 0\ 1/4]. \end{aligned} \quad (18)$$

Similarly, we modify the green channel update equation as follows:

$$\begin{aligned}\tilde{\Delta}_{g,r}(i,j) &= \hat{\Delta}_{g,r}(i,j).(1-w) \\ &+[w_N.(\hat{\Delta}_{g,r}(i-2,j-1)+\hat{\Delta}_{g,r}(i-2,j+1) \\ &+\hat{\Delta}_{g,r}(i-4,j))/3 w_S.(\hat{\Delta}_{g,r}(i+2,j-1) \\ &+\hat{\Delta}_{g,r}(i+2,j+1)+\hat{\Delta}_{g,r}(i+4,j))/3 \\ & w_E.\hat{\Delta}_{g,r}(i,j-2)+w_W.\hat{\Delta}_{g,r}(i,j+2)].w/w_T \\ w_T &= w_N + w_S + w_E + w_W. \end{aligned} \quad (19)$$

And finally, the red and blue channel interpolation requires modification as well. We estimate the missing red and blue samples using the closest color difference estimates. For the red channel interpolation, the pixels on green&blue rows use estimates from three neighbors and the ones on green&red rows use four:

$$\begin{aligned}\tilde{R}(i,j) &= G(i,j) - \frac{\tilde{G}(i+1,j)-R(i+1,j)}{2} \\ &- \frac{\tilde{G}(i-1,j-1)-R(i-1,j-1)+\tilde{G}(i-1,j+1)-R(i-1,j+1)}{4} \\ \tilde{R}(i,j-1) &= G(i,j-1) - \frac{\tilde{G}(i-1,j-1)-R(i-1,j-1)}{2} \\ &- \frac{\tilde{G}(i+1,j-2)-R(i+1,j-2)+\tilde{G}(i+1,j)-R(i+1,j)}{4} \\ \tilde{R}(i-1,j) &= G(i-1,j) \\ &- \frac{\tilde{G}(i-1,j-1)-R(i-1,j-1)+\tilde{G}(i-1,j+1)-R(i-1,j+1)}{2.5} \\ &- \frac{\tilde{G}(i-3,j)-R(i-3,j)+\tilde{G}(i+1,j)-R(i+1,j)}{10}. \end{aligned}$$

Although we needed to make several changes to apply the algorithm to the Lukac pattern, the main structure of the method is maintained.

IV. CONCLUSION

Most digital cameras use a color filter array to capture the colors of the scene. Downsampled versions of the red, green, and blue components are acquired, and an interpolation of the three colors is necessary to reconstruct a full representation of the image. This color interpolation is known as demosaicing. Propose a demosaicing method that uses multiscale color gradients to adaptively combine color difference estimates from different directions. The proposed solution does not require any thresholds since it does not make any hard decisions, and it is noniterative**.**

In the proposed system demosaicing based on Bayer and other RGB pattern (eg.Lukac pattern) and Compare the performance by using PSNR and MSE values. Efficiency of each one to be find out.

Here A directional CFA interpolation method that is based on multiscale color gradients. The developed method is applied to Bayer and Lukac patterns with great results which shows that the relationship between gradients at different scales can be a very effective feature to optimally combine directional estimates. This method,the horizontal and vertical color difference estimates are blended based on the ratio of the total absolute values of vertical and horizontal color difference gradients over a local window.

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