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NOVEL COLOR FILTER ARRAY DEMOSAICING IN FREQUENCY DOMAIN WITH SPATIAL REFINEMENT

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ABSTRACT

The main idea behind wavelet based demosaicing with spatial refinement is to reconstruct the full resolution color image from the mosaiced image. In this study, a new effective wavelet based demosaicing algorithm for interpolating the missing color components in Bayer's Color Filter Array (CFA) pattern is proposed. This interpolation technique uses the interchannel correlation among the high frequency subbands to determine the missing pixels in each color channel, followed by a refining step in spatial domain which uses non-iterative technique that enforces color difference rule with fewer computations. As a result, the proposed demosaicing method yields better performance than bilinear, edge based and subband based demosaicing methods.

Keywords: Bayer's CFA, Color Difference Rule, Demosaicing, Interchannel Correlation, Wavelet

1. INTRODUCTION

Digital cameras use a Charge Coupled Device (CCD) to capture the color signal of objects. The color filter array is placed between the lens and the sensors in the charge coupled device. CFA has one color filter element for each sensor and it manages one color sample at a time. The CFA is used to capture all three color channels at the same time and reducing the complexity and cost of the digital cameras. The Bayer pattern shown in **Fig. 1** is widely used CFA pattern (Bayer, 1976) in which, the sampling of Green (G) color component is twice as compared to Red (R) and Blue (B) color components. At each pixel only one color component is present, the missing two colors have to be interpolated from the existing pixels. The process of reconstructing a full resolution color image from Bayer sample is known as CFA demosaicing. The improper demosaicing method leads to visual artifacts that are around edges and color misregistration artifacts that degrade the color resolution.

The different approaches have been applied for demosaicing algorithm are as follows: The first category is the simple non adaptive algorithms such as nearest neighborhood (Jean, 2010), bilinear interpolation (Blu, 2004), that is used to interpolate the missing pixel values. The bilinear interpolation is the simplest color interpolation method (Kim *et al*., 2006; Mohanbabu and Renuga, 2012). In bilinear interpolation, the missing color components are calculated by taking average of neighbouring pixels to determine the missing green, red and blue color of each pixel (Jean, 2010; David *et al*., 2002). It blurs the edge region of the resulting image because of the absence of object boundaries and produces the highly visible artifacts.

The second category demosaicing algorithm uses interchannel and intra channel correlation (Nakanishi *et al*., 1998; Cok, 1987; Lukac and Plataniotis, 2004; Lukac *et al*., 2004) to interpolate the missing color components. Intra channel correlation is based on the fact that the color values of the neighbouring pixels have small variations. The

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missing pixels can be interpolated with the use of neighbouring pixels. Inter channel correlation (Cok, 1987; Pei and Tam, 2003; Weldy, 1988; Adams, 1995) uses color ratio rule (Kimmel, 1999) and color difference rule (Pei and Tam, 2003; Su, 2006) which exploit the correlation among color planes. Color difference rule is mainly used in many algorithms (Pei and Tam, 2003; Su, 2006; Kim *et al*., 2010; Chen *et al*., 2012) due to its simplicity. The color difference rule states that the difference between two color channels (R, G, B and G) in every pixel location within a boundary is nearly a constant value.

The third category is edge-directed interpolation which is an adaptive approach that detects spatial features present in the neighborhood pixel (Newlin and Monie, 2013; Baharav and Kakarala, 2002; Laroche and Prescott, 1994; Hibbard, 1995; Adams and Hamilton Jr, 1996; Li and Orchard, 2001; Kim *et al*., 2010; Chen *et al*., 2012). The direction of edge is estimated by the horizontal and vertical gradients (Hwang and Lee, 2004) from the color images. The missing color components can be calculated along the edges of the image. The resulting demosaiced images are sharper with less blurring artifacts (Chen *et al*., 2008). This algorithm provides the good quality on the edge region but it yields poor result in problematic regions of the image.

The fourth category explains the subband interpolation (Lin and Su, 2007; Chen *et al*., 2008; Driesen and Scheunders, 2004). In frequency domain, the color planes are divided into series of subbands with different frequency information. The low frequency band gives the coarse information about the images. High pass bands reveal the fine information in images which corresponds to edges. There exists a strong correlation between the high frequency bands of different color planes (Chen *et al*., 2008). For interpolation, the demosaicing algorithms (Altunbasak *et al*., 2002; Chen *et al*., 2008; Su and Kao, 2009) mainly uses highly correlated high frequency bands. The demosaicing algorithms (Altunbasak *et al*., 2002; Li, 2005; Chen *et al*., 2008) are iterative, that introduces high computations.

In Wavelet-based color filter array demosaicing (Chen *et al*., 2008) starts with the bilinear interpolation which acts as an initial interpolation technique. This initial interpolation algorithm uses the intra channel interpolation. Down-sampled images are formed from the initially interpolated image. The high frequency sub-bands of missing down-sampled images are interpolated with the help of high frequency components of other known color planes. Finally an iterative subband method is used for artifact reduction.

Although subband synthesis algorithm produces better results than previous algorithms, the algorithm needs too many computations due to its iterative artifact reduction method. The proposed method replaces this iterative method by a non-iterative technique which exploits inter channel correlation in spatial domain. The initial estimation with bilinear interpolation is fine tuned using adaptive edge based color plane interpolation (Kim *et al*., 2006; Chen *et al*., 2012). The proposed algorithm uses both spatial and frequency domain techniques during interpolation.

This study is organized as follows, section II explains the proposed method and each sub section explains each part of the system. Section III briefs the steps involved in the proposed methodology. Section IV reports the experimental results. CPSNR and PSNR are used as comparative measure. Here 24 Kodak images database are used for comparison between various demosaicing methods with the proposed algorithm.

2. WAVELET BASED DEMOSAICING WITH SPATIAL REFINEMENT

The demosaicing algorithm starts with bilinear interpolation technique to interpolate missing R, G, B colors. Although these algorithms are computationally efficient, but due to their fixed pattern of interpolation without considering edges of object, creates artifacts. Since edges play a main role in images, interpolation of channel is done by considering the direction of edges. Then the interpolated image is subdivided into subimages and 2D discrete wavelet transform is applied to separate each color channel into Low-Low (LL), Low-High (LH), High-Low (HL) and High-High (HH) subbands. Then the coefficients of the wavelet transform are modified by making use of inter channel correlation. After updation, inverse discrete wavelet transform is applied to bring back to spatial domain and post processing is done using color difference rule. The algorithm flow is shown in **Fig. 2.**

2.1. Bilinear Interpolation

Bilinear interpolation is an upsampling method that uses the distance-weighted average of the four nearest pixel values to estimate a missing pixel value. This interpolation method takes pixels in the Bayer pattern and ignores the information about the edge regions. Bilinear algorithm interpolates every missing pixels in a fixed pattern. The missing pixel values are calculated by taking average value of the four adjacent pixels in each color plane. This introduces large errors that lead to blur the interpolated image.

The green, red and blue color components are interpolated using the equations given in Demosaicing with the Bayer Pattern (Jean, 2010).

2.2. Edge Adaptive Interpolation

Edge adaptive method is an adaptive approach that is used to interpolate the missing pixel values along the edge patterns of the color channels. In this method, the edge directions such as horizontal and vertical directions are calculated according to the edge region (Pei and Tam, 2003; Chang and Chen, 2012; Gunturk *et al*., 2005). The edge directions are defined by the horizontal and vertical gradients to detect the pixel location. This interpolation is used to avoid choosing the direction across edges. The horizontal and vertical gradients are compared, if the horizontal gradient is greater than the interpolation is along vertical direction. If the vertical gradient is greater, then the green channel is estimate along the horizontal direction. If the horizontal and vertical gradients are equal then the interpolation is calculated by taking the average of its four neighbouring pixels. The missing green pixel location can be obtained from the neighbouring green pixels (Kim *et al*., 2006).

The missing green pixel G (4, 3) in **Fig. 1** at blue row can be estimated by using Equation 1 and 2:

$$\begin{aligned}\Delta H &= [G(4,2)-G(4,4)]+[2B(4,3)-B(4,1)-B(4,5)\\ \Delta V &= [G(3,3)-G(5,3)]+[2B(4,3)-B(2,3)-B(6,3)\end{aligned} \quad (1)$$

$$G(4,3)=\begin{cases}\dfrac{G(4,2)+G(4,4)}{2}+\dfrac{2B(4,3)-B(4,1)-B(4,5)}{4}, \text{if}\Delta H\langle\Delta V\\ \dfrac{G(3,3)+G(5,3)}{2}+\dfrac{2B(4,3)-B(2,3)-B(6,3)}{4}, \text{if}\Delta H\rangle\Delta V\\ \dfrac{G(3,2)+G(5,4)+G(3,4)+G(5,2)}{4}+\dfrac{4B(4,3)-B(4,1)-B(4,5)-B(2,3)-B(6,3)}{8}, \text{if}\Delta H=\Delta V\end{cases} \quad (2)$$

The missing green pixel G(3,4) at Red row can be estimated using Equation 3 and 4 as follows:

$$\begin{aligned}\Delta H &= [G(3,3)-G(3,5)]+[2R(3,4)-R(3,2)-R(3,6)\\ \Delta V &= [G(3,3)-G(3,5)]+[2R(3,4)-R(1,4)-R(5,4)\end{aligned} \quad (3)$$

$$G(4,3)=\begin{cases}\dfrac{G(3,3)+G(3,5)}{2}+\dfrac{2R(3,4)-R(3,2)-R(3,6)}{4}, \text{if}\Delta H\langle\Delta V\\ \dfrac{G(2,4)+G(4,4)}{2}+\dfrac{2R(3,4)-R(1,4)-R(5,4)}{4}, \text{if}\Delta H\rangle\Delta V\\ \dfrac{G(2,3)+G(4,5)+G(2,5)+G(4,3)}{4}+\dfrac{4R(3,4)-R(3,2)-R(3,6)-R(1,4)-R(5,4)}{8}, \text{if}\Delta H=\Delta V\end{cases} \quad (4)$$

ΔH and ΔV are horizontal and vertical gradient functions used to find edge directions.

2.3. Wavelet Demosaicing

The wavelet based demosaicing method is based on the fact that the high frequency subbands {LH, HL, HH} of different color planes are highly correlated (Chen *et al*., 2008) and have constant variation between the color planes which is proved by using Mean Absolute Error (MAE) metric in (Chen *et al*., 2008). This property can be used to update the high frequency subband coefficients of the interpolated color pixels with the help of high frequency subbands of known color pixels.

In **Fig. 3** the pixels with '*'are the color pixels obtained from Bayer's pattern. All other pixels are missing pixels in Bayer's pattern found out by using initial interpolation (Bilinear interpolation and edge adaptive interpolation).

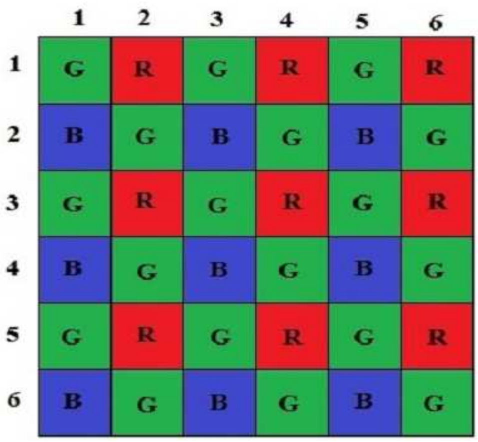

Fig. 1. Bayer CFA

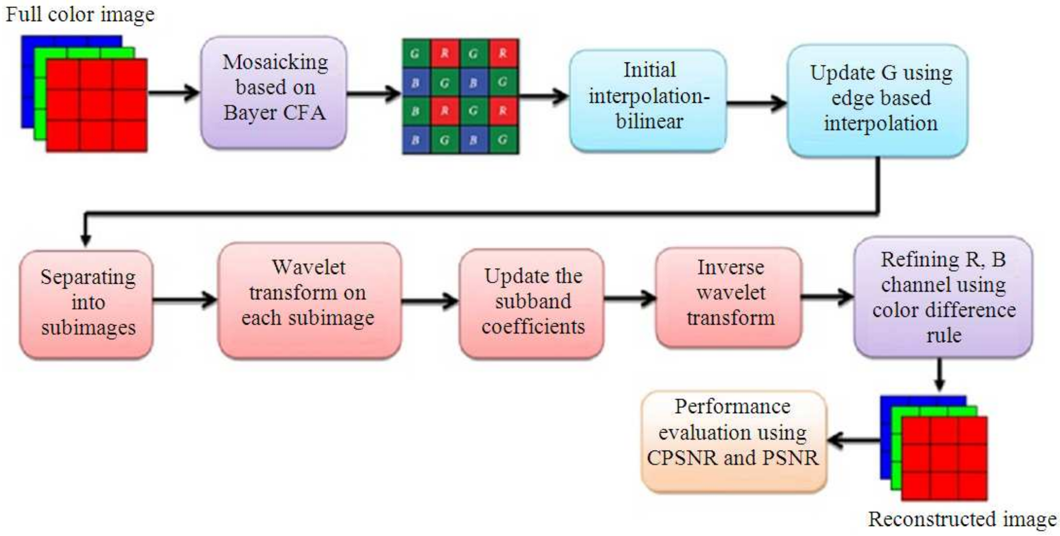

Fig. 2. Wavelet based demosaicing with spatial refinement

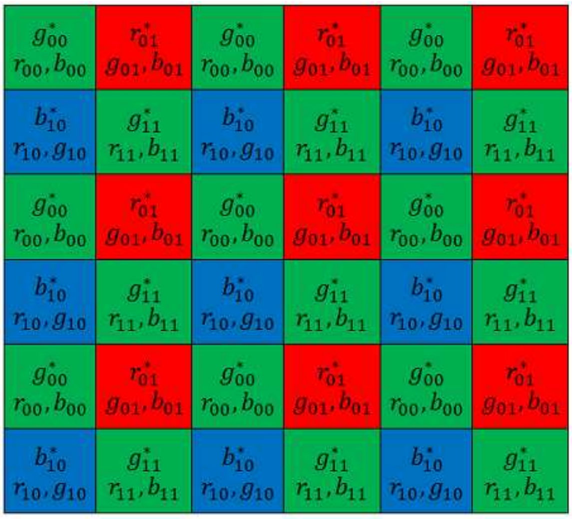

Fig. 3. Sub-images for RGB color planes

The interpolated color image is separated into subimages according to the positions in Bayer's array {00, 01, 10, 11} for each color channel. The subimages are formed by collecting all pixels having same subscript and a total of 12 subimages are formed (r_{00}, r_{01}, r_{10}, r_{11}, g_{00}, g_{01}, g_{10}, g_{11}, b_{00}, b_{01}, b_{10}, b_{11}). Each subimage is divided into four frequency bands {LL, LH, HL, HH} using Two Dimensional Discrete Wavelet Transform (2D-DWT). The high frequency subbands {LH, HL, HH} of interpolated pixels are updated from observed pixels (g_{00}, g_{11}, r_{01}, b_{10}) in CFA.

2.4. Refining R and B at "00" place

In '00' positions g_{00} is the known color. The missing other two colors R and B have to be refined with the help of g_{00}:

$$\left.\begin{aligned} r_{00} &= g_{00} - (mr_{00} * g_{00}) + (mr_{00} * r_{00}) \\ b_{00} &= g_{00} - (mb_{00} * g_{00}) + (mb_{00} * b_{00}) \end{aligned}\right\} \quad (5)$$

2.5. Refining G and B at "01" place:

$$\left.\begin{aligned} g_{01} &= r_{01} - (mg_{01} * r_{01}) + (mg_{01} * g_{01}) \\ b_{01} &= r_{01} - (mb_{01} * r_{01}) + (mb_{01} * b_{01}) \end{aligned}\right\} \quad (6)$$

2.6. Refining G and R at "10" place:

$$\left.\begin{aligned} g_{10} &= b_{10} - (mg_{10} * b_{10}) + (mg_{10} * g_{10}) \\ r_{10} &= b_{10} - (mr_{10} * b_{10}) + (mr_{10} * r_{10}) \end{aligned}\right\} \quad (7)$$

2.7. Refining R and B at "11" place:

$$\left.\begin{aligned} r_{11} &= g_{11} - (mr_{11} * g_{11}) + (mr_{11} * r_{11}) \\ b_{11} &= g_{11} - (mb_{11} * g_{11}) + (mb_{11} * b_{11}) \end{aligned}\right\} \quad (8)$$

where, the script 'm' denotes the mean of the corresponding subband. The equations are applied only to high pass bands {HH, HL, LH}. The Low pass band

{LL} coefficients are not updated. The subimages are converted back to spatial domain using 2D-IDWT.

2.8. Spatial Refinement

In subband synthesis demosaicing (Chen *et al*., 2008) the refining of demosaiced color planes are done in frequency domain using wavelet transform and the refining procedure was iterative. This needs many computations. These complexities are solved by using a spatial non iterative technique that reduces the complexity.

During the refinement step red and blue channels are alone updated leaving green channel unaltered. Since in Bayer's pattern 50% of the pixels are green, 25% of the pixels are red and 25% of the pixels are blue more number of red and blue pixels are interpolated pixels compared to green pixels. So red and blue pixels are more prone to errors. The red and blue pixels are refined using color difference rule which is used as a tool to explore interchannel correlation (Li, 2005).

The expression for finding color difference signals are found by taking the difference between the red and green and blue and green channel. Due to the majority of green pixels 'G' is taken as reference:

$$CD_R = G - R \quad CD_B = G - B \tag{9}$$

The color difference signals CD_R and CD_B are found in every pixel location. The Bayer pattern in **Fig. 1** is taken as reference to refine the procedure. The native green pixels are considered as two categories, green pixel at the red pixel row and green pixel at blue pixel row.

The blue pixel at native green pixel (blue pixel row) is refined by:

$$\begin{aligned} CD_B(2,2) &= \frac{1}{2}\left[CD_B(2,1) + CD_B(2,3)\right] \\ B(2,2) &= G(2,2) + CD_B(2,2) \end{aligned} \tag{10}$$

The blue pixel at native green pixel (red pixel row) is refined by:

$$\begin{aligned} CD_B(3,3) &= \frac{1}{2}\left[CD_B(2,3) + CD_B(4,3)\right] \\ B(3,3) &= G(3,3) + CD_B(3,3) \end{aligned} \tag{11}$$

Likewise blue pixels in all native green pixel locations are refined.

The blue pixels at native red pixels are refined by:

$$\begin{aligned} CD_B(3,2) &= \frac{1}{4}\begin{bmatrix} CD_R(2,2) + CD_R(4,2) \\ +CD_R(3,1) + CD_R(3,3) \end{bmatrix} \\ B(3,2) &= G(3,2) + CD_B(3,2) \end{aligned} \tag{12}$$

Likewise blue pixels in all native red pixel locations are refined. The red pixels are refined in similar manner of blue pixel. The procedure used for refining uses simple expressions hence no complex processing required as compared to subband based demosaicing method (Chen *et al*., 2008).

The performance of the proposed work is measured in terms of CPSNR for whole image and PSNR for each channel. These performance measures are comparative which takes original input image as reference which reflects how far the reconstructed image resembles like original input image (Kim *et al*., 2006; Jean, 2010; Tian *et al*., 2012; Fan *et al*., 2013). The CPSNR and PSNR measurement can be defined as follows Equation 13 and 14:

$$\left.\begin{aligned} CPSNR &= 10\log_{10}\left(\frac{255^2}{CMSE}\right) \\ CMSE &= \frac{1}{3HW}\sum_{k=R,G,B}\sum_{i=1}^{H}\sum_{j=1}^{W}\left(I_0^k(i,j) - I_d^k(i,j)\right)^2 \end{aligned}\right\} \tag{13}$$

$$PSNR = 10\log_{10}\left(\frac{255^2 HW}{\left(I_0^k(i,j) - I_d^k(i,j)\right)^2}\right) \tag{14}$$

Where:

H,W = The height and width of image,
$I_0^k(i,j)$ = The original image,
$I_d^k(i,j)$ = The reconstructed image using demosaicing algorithm
K = The corresponding color plane (R,G,B).

The steps involved in Wavelet based demosaicing with spatial refinement are as follows.

2.9. Initial Interpolation

The missing pixels in Bayer pattern are interpolated using bilinear interpolation algorithm (Jean, 2010) which uses intra channel correlation for interpolation.

2.10. Edge Based Interpolation

Since edges play a main role in enhancing the image. Inorder to reduce the errors during interpolation, interpolation is done along edge directions by using edge adaptive interpolation using the Equation 1-4.

2.11. Wavelet Demosaicing

The image is divided into four subimages g_{00},r_{01}, b_{10}, g_{11}.

2D-DWT is applied to all subimges to produce four subbands {LL, LH, HL, HH}.

The high frequency components of each sub image is updated by using Equation (5-8).

Inverse 2D-DWT is applied to synthesis the subimages.

2.12. Refining Step

Non Iterative algorithm which makes use of inter-channel interpolation is used to refine the Red and Blue color values as per Equation (9-12).

3. RESULTS

In this study, the wavelet based demosaicing with spatial refinement technique is compared with the previous interpolation methods such as bilinear interpolation, edge based interpolation and subband synthesis demosaicing algorithms. The performance measures are estimated by using 24 kodak images shown in **Fig. 4** with size 768×512 pixels.

The CPSNR values are tabulated in **Table 1**. It is clear that, the proposed method gives better CPSNR values than the existing demosaicing algorithms.

Fig. 4. Kodak test images: In the order of left to right from top to bottom

Table 1. CPSNR values for 24 kodak test images

Img	Bilinear	Edge based	Subband synthesis	Wavelet with spatial refinement
1	30.7730	31.2458	39.5224	40.6942
2	36.6873	37.0425	39.5198	41.3527
3	37.6775	38.0647	43.3218	43.9651
4	37.4213	37.8047	41.4224	43.4641
5	31.2157	31.8233	38.6369	40.5972
6	32.1414	32.5964	40.2550	41.9364
7	37.1797	37.6152	42.1956	44.6154
8	28.2879	28.7457	36.0158	38.9305
9	36.4896	36.9292	43.2609	45.2354
10	36.3952	36.8716	43.5337	45.2596
11	33.6645	34.1372	41.0060	42.9933
12	36.9695	37.3912	43.5063	46.4256
13	28.6113	29.1087	37.2893	37.3747
14	33.4690	33.9611	36.7377	38.7378
15	35.4486	35.8213	39.8739	42.0606
16	35.2366	35.6156	43.2864	44.6285
17	36.6810	37.2463	43.6912	44.4829
18	32.5620	33.0611	38.9911	40.0813
19	32.7829	33.2797	40.5543	43.9703
20	34.6422	34.9845	41.2988	42.7135
21	33.0627	33.5363	40.9836	41.8151
22	34.9277	35.3907	39.4920	40.9682
23	38.3544	38.7374	42.7698	43.9694
24	31.4110	31.8746	37.6036	38.0094

Table 2. PSNR values for each color channel 24 kodak test images

Img	Bilinear			Edge based			Subband synthesis			Wavelet with spatial refinement		
	R	G	B	R	G	B	R	G	B	R	G	B
1	29.741	34.286	29.678	29.741	39.442	29.678	38.881	40.591	39.272	39.811	42.617	40.154
2	35.022	40.797	36.100	35.022	44.854	36.100	36.524	43.533	41.665	39.147	44.034	42.327
3	35.942	41.591	37.252	35.942	45.912	37.252	42.825	45.853	42.113	43.217	46.289	43.078
4	37.106	41.126	35.663	37.106	45.051	35.663	37.928	46.396	44.927	40.751	46.799	45.211
5	30.126	34.082	30.430	30.126	40.240	30.430	37.853	41.500	37.547	39.959	42.717	39.705
6	30.803	35.699	31.355	30.803	40.606	31.355	39.616	41.921	39.609	41.342	44.180	40.943
7	35.514	41.092	36.662	35.514	46.389	36.662	42.159	45.984	40.226	44.156	47.043	43.420
8	27.104	32.181	27.220	27.104	37.959	27.220	34.998	37.820	35.697	37.959	41.183	38.307
9	36.102	40.438	34.717	36.102	45.917	34.717	42.785	45.225	42.298	44.552	46.919	44.624
10	36.272	40.017	34.528	36.272	45.509	34.528	41.980	46.187	43.416	44.351	47.456	44.598
11	32.269	37.035	33.016	32.269	41.880	33.016	39.313	43.338	41.279	41.738	45.071	42.801
12	35.266	41.164	36.404	35.266	36.404	36.404	42.376	46.138	42.872	45.619	48.716	45.612
13	27.650	31.312	27.764	27.650	35.342	27.764	37.443	38.584	36.173	37.128	39.053	36.363
14	32.123	36.675	32.828	32.123	41.524	32.828	34.990	40.838	36.262	37.767	41.174	38.021
15	34.216	39.315	34.439	34.216	43.306	34.439	37.339	43.381	41.055	39.927	44.670	42.936
16	33.815	39.277	34.378	33.815	43.662	34.378	43.143	44.836	42.260	43.632	46.928	44.008
17	36.205	39.248	35.440	36.205	43.949	35.440	43.318	45.433	42.754	43.964	46.035	43.786
18	31.906	35.128	31.478	31.906	38.980	31.478	37.865	41.464	38.428	39.039	41.776	39.860
19	31.592	36.521	31.772	31.592	42.845	31.772	39.476	42.313	40.337	42.768	45.944	43.773
20	33.838	39.032	33.080	33.838	43.287	33.080	41.613	44.279	39.349	42.673	45.111	41.206
21	31.892	36.279	32.221	31.892	40.838	32.221	40.720	42.780	39.923	41.446	43.773	40.762
22	33.866	38.111	33.983	33.866	42.446	33.983	38.562	42.531	38.472	39.964	43.059	40.467
23	36.114	42.556	38.598	36.114	47.324	38.598	41.226	46.550	42.145	42.076	47.010	44.159
24	31.062	34.104	30.016	31.062	37.717	30.016	37.292	40.023	36.291	37.664	40.261	36.797

The CPSNR values are calculated by performing the MATLAB source code. The average CPSNR of the proposed demosaicing method is increased than the other three interpolation methods.

The **Table 2** shows the PSNR values for every color channels. From the results, it can be observed that for edge based interpolation, G channel PSNR is improved compared to bilinear method. Subband synthesis method shows better performance than other two algorithms due to processing of high pass bands and a wavelet based post processing technique. The proposed method has better PSNR values for every color channel compared to other demosaicing algorithms.

4. CONCLUSION

In this study, an effective demosaicing algorithm has proposed, which uses both spatial and frequency technique for interpolation. The edge adaptive color plane interpolation is used to determine the edge direction of the missing pixel by using the neighbouring color components directional information. Wavelet based demosaicing method is used to estimate the missing pixels by interchannel correlation among high frequency subbands. This enhances the fine details in the image and reduces the color artifacts with less computation. The spatial refinement technique enforces the color difference rule to refine the missing color components. The experimental result shows that the proposed demosaicing technique yields better performance than other existing interpolation methods such as bilinear, edge based and subband based interpolation methods and produces the better quality image.

5. REFERENCES

Adams, J.E. and J.F. Hamilton Jr, 1996. Adaptive color plane interpolation in single color electronic camera. U.S. Patent, 5: 506-619.

Adams, J.E., 1995. Interactions between color plane interpolation and other image processing functions in electronic photography. Proc. SPIE., 2416: 144-151. DOI: 10.1117/12.204825

Altunbasak, Y., B.K. Gunturk and R.M. Mersereau, 2002. Color plane interpolation using alternating projections. IEEE Trans. Image Proc., 11: 997-1013. DOI: 10.1109/TIP.2002.801121

Gunturk, B.K., J. Glotzbach, Y. Altunbasak, R.W. Schafer and R.M. Mersereau, 2005. Demosaicking: Color filter array interpolation. IEEE Signal Proc. Mag., 22: 44-54. DOI: 10.1109/MSP.2005.1407714

Baharav, Z. and R. Kakarala, 2002. Adaptive demosaicing with the principal vector method. IEEE Trans. Consumer. Electron., 48: 932-937. DOI: 10.1109/TCE.2003.1196423

Bayer, B.E., 1976. Color imaging array. U.S. Patent, 3: 971- 965.

Blu, T., P. Thevenaz and M. Unser, 2004. Linear interpolation revitalized. IEEE Trans. Image Process., 13: 710-719. DOI: 10.1109/TIP.2004.826093

Chang, P.Y. and W.J. Chen, 2012. Effective demosaicking algorithm based on edge property for color filter arrays. Elsevier. Digital Signal Proc., 22: 163-169. DOI: 10.1016/j.dsp.2011.09.006

Chen, L., K.H. Yap and Y. He, 2008. Subband synthesis for color filter array demosaicking. IEEE Trans. Syst. Man Cybernet. Syst. Humans. 38: 485-492. DOI: 10.1109/TSMCA.2007.914740

Chen, W.G., Wang, X. and J.G. Xing, 2012. Colour demosaicking for complementary colour filter array using spectral and spatial correlations. IET Image Proc., 6: 901-909. DOI: 10.1049/iet-ipr.2011.0248

Cok, D.R., 1987. Signal processing method and apparatus for producing interpolated chrominance values in a sampled color image signal. U.S. Patent, 4: 642-678.

David, H., P.B. Brainard, P.L. Delahunt and Z. Xuemei, 2002. Perceptual assessment of demosaicing algorithm performance. Proc. IEEE, 90: 123-132. DOI: 10.1109/5.982410

Driesen, J. and P. Scheunders, 2004. Wavelet-based color filter array demosaicking. Proceedings of the International Conference on Image Processing, Oct. 24-27, IEEE Xplore Press, pp: 3311-3314. DOI: 10.1109/ICIP.2004.1421822

Fan, Y.C., Y.F. Chiang and Y.T. Hsieh, 2013. Constant-hue-based color filter array demosaicking sensor for digital still camera implementation. IEEE Sens. J., 13: 2586-2594. DOI: 10.1109/JSEN.2013.2256779

Hibbard, R.H., 1995. Apparatus and method for adaptively interpolating a full color image utilizing luminance gradients. U.S. Patent, 5: 382-976.

Hwang, J.W. and H.S. Lee, 2004. Adaptive image interpolation based on local gradient features. IEEE Signal Proc. Lett., 11: 359-362. DOI: 10.1109/LSP.2003.821718

Kim, J., L. Seongjoo and L. Wonjae, 2006. Cost-efffective color filter array demosaicing using spatial correlation. IEEE Trans. Consumer Electron., 52: 547-554. DOI: 10.1109/TCE.2006.1649678

Jean, R., 2010. Demosaicing with the bayer pattern. University of North Carolina.

Kim, C.W., H.M. Oh, M.G. Kang and Y.S. Han, 2010. Edge adaptive color demosaicking based on the spatial correlation of the bayer color difference. Eur. J. Image Video Proc., 2011: 874364-874364. DOI: 10.1155/2010/874364

Kimmel, R., 1999. Demosaicing: Image reconstruction from CCD samples. IEEE Trans. Image Proc., 8: 1221-1228. DOI: 10.1109/83.784434

Laroche, C.A. and M.A. Prescott, 1994. Apparatus and method for adaptively interpolating a full color image utilizing chrominance gradients. U.S. Patent, 5: 373-322.

Li, X. and M.T. Orchard, 2001. New edge directed interpolation. IEEE Trans. Image Proc., 10: 1521-1527. DOI: 10.1109/83.951537

Li, X., 2005. Demosaicing by successive approximation. IEEE Trans. Image Proc., 14: 370-379. DOI: 10.1109/TIP.2004.840683

Lin, Y.S. and C.Y. Su, 2007. Colour interpolation using wavelet-based classifiers. Electronics Lett., 43: 667-669. DOI: 10.1049/el:20070333

Lukac, R. and K.N. Plataniotis, 2004. Normalized color-ratio modeling for cfa interpolation. IEEE Trans. Consum. Electron., 50: 737-745. DOI: 10.1109/TCE.2004.1309456

Lukac, R., K. Martin and K.N. Plataniotis, 2004. Demosaicked image postprocessing using local color ratios. IEEE Trans. Circuits Syst. Video Technol., 14: 914-920. DOI: 10.1109/TCSVT.2004.828316

Mohanbabu, G. and P. Renuga, 2012. Chroma subsampling based compression of bayer-pattern video sequences using gradient based interpolation. Eur. J. Sci. Res., 86: 556-564.

Nakanishi, C., T. Hase and T. Sakamoto, 1998. Software pixel interpolation for digital still cameras suitable for a 32-Bit MCU. IEEE Trans. Consum. Electron., 44: 1342-1352. DOI: 10.1109/30.735836

Pei, S.C. and I.K. Tam, 2003. Effective color interpolation in CCD color filter arrays using signal correlation. IEEE Trans. Circuits Syst. Video Technol., 13: 503-513. DOI: 10.1109/TCSVT.2003.813422

Su, C.Y. and W.C. Kao, 2009. Effective demosaicing using subband correlation. IEEE Trans. Consumer Electron., 55: 199-204. DOI: 10.1109/TCE.2009.4814435

Su, C.Y., 2006. Highly effective iterative demosaicing using weighted-edge and color-difference interpolations. IEEE Trans. Consumer Electron., 52: 639-645. DOI: 10.1109/TCE.2006.1649690

Tian, M., Q. Tian and X. Yang, 2012. Adaptive region demosaicking using multi-gradients. Proc. Eng., 29: 2199-2203. DOI: 10.1016/j.proeng.2012.01.287

Weldy, J.A., 1988. Optimized design for a single-sensor color electronic camera system. Proc. Spie., 1071: 300-307. DOI:10.1117/12.952531

Newlin, D.R. and E.C. Monie, 2013. Edge sensing demosaicing using adaptive weighted interpolation. Am. J. Applied Sci.., 10: 418-425. DOI: 10.3844/ajassp.2013.418.425