Enhanced Integrated Gradient And Its Applications To Color Demosaicing

King-Hong Chung
EIE Department
The Hong Kong Polytechnic University
Hong Kong

Yuk-Hee Chan
EIE Department
The Hong Kong Polytechnic University
Hong Kong

Abstract—In this paper, an effective decision-based demosaicing algorithm for Bayer images is presented. An enhanced edge-sensing measure called enhanced integrated gradient (EIG) is exploited to guide the interpolation along the edges. This measure improves the recently proposed integrated gradient (IG) and hence can support more gradient information from various color intensity and color difference planes under the directional compatibility constraint. An adaptive green plane enhancement which works with the EIG is also proposed to further improve the efficiency of the algorithm.

Keywords-component; color demosaicing, CFA, integrated gradient

I. INTRODUCTION

To reduce cost, most digital cameras acquire color scenes with a single image sensor. Over the sensor, the Bayer color filter array (CFA) [1] as shown in Fig. 1 is coated to record one of the three primary colors at each pixel. A process which interpolates the two missing color samples of each pixel is then carried out to convert the mosaic Bayer images to full color. This process is called color demosaicing, which is critical as it determines the camera output image quality.

Many demosaicing methods have been proposed in the literatures [2,3]. Many of them detect edge orientation and interpolate missing color components accordingly [4-7]. In [8], Chung et. al. proposed an integrated gradient (IG) to consider the CI and CD gradient information at the same time to decide the interpolation direction. This method can improve demosaicing performance in fine detail areas. However, because of the asymmetric sampling arrangement of the Bayer CFA and the constraint that the gradient information has to be directionally compatible for comparison at each Bayer sampling position, the CI gradient information carried by the IG is extracted from one of the three color planes only. Consequently, when there is a sharp change over the edge in the two other color planes only, an inappropriate interpolation direction may be selected and hence visual artifacts may be introduced.

In this paper, an enhanced edge-sensing measure called enhanced integrated gradient (EIG) is proposed. Unlike IG, EIG carries the CI gradient information of all color planes. By replacing IG, EIG can be used to develop a new demosaicing algorithm the performance of which is even better than [8].

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II. ENHANCED INTEGRATED GRADIENT EXTRACTION

This section introduces a newly defined gradient measure called enhanced integrated gradient (EIG), which is used in various stages to guide the interpolations at each pixel. EIG improves our previously proposed integrated gradient [8] to combine more gradient information from various color intensity (CI) and color difference (CD) planes simultaneously, and hence can provide more complete directional gradient information for one to reach a better decision in selecting the interpolation direction.

Without loss of generality, let us consider the case shown in Fig. 1(b) as an example to define the EIG of a pixel. Each pixel has four EIGs, one for each direction. For the case shown in Fig. 1(b), the eastbound EIG of the pixel \((i, j)\) is defined as

\[
\hat{c}_{E}^{E_{i,j}} = 2\Lambda_{GR}^{E_{i,j}}(i,j) + \Lambda_{BG}^{E_{i,j}}(i-1,j) + \Lambda_{BG}^{E_{i,j}}(i+1,j),
\]

where

\[
\Lambda_{XY}^{E_{i,j}}(m,n) = \hat{X}_{X,Y}^{E_{i,j}}(m,n) + a\hat{X}_{X,Y}^{E_{i,j}}(m,n)
\]

is a weighted sum of the eastbound CI gradient \(\hat{X}_{X,Y}^{E_{i,j}}(m,n)\) and the eastbound CD gradient \(\hat{X}_{X,Y}^{E_{i,j}}(m,n)\) of pixel \((m,n)\), and \(a\) is a weighting factor used to control the contribution of the two gradients.

The CI gradient \(\hat{X}_{X,Y}^{E_{i,j}}(m,n)\) measures the extent of eastbound CI change and is defined on the color channels that contain the Bayer samples in the \(m^{th}\) row. Specifically, we have

\[
\hat{X}_{X,Y}^{E_{i,j}}(m,n) = \frac{1}{2}[X_{m,n} - X_{m,n+1}] + \frac{1}{2}[Y_{m,n} - Y_{m,n-1}]
\]

where \(X_{m,n}\) and \(Y_{m,n}\) are, respectively, the known Bayer sample at positions \((m,n)\) and \((m,n-1)\).

Fig. 1 Four Bayer regions with their center pixels having (a)-(b) green, (c) red and (d) blue Bayer samples respectively.
The CD gradient $\tilde{N}_{X,Y}^E(m,n)$ provides supplementary edge detection information by evaluating the CD change of two successive pixels along the same eastbound direction. In formulation, it is defined as

$$\tilde{N}_{X,Y}^E(m,n) = \frac{1}{2} \sum_{i=0,1} | d_{XY}(m,n+l) - d_{XY}(m,n+l+1) |$$

where $d_{XY}(m,n)$ represents the X-Y CD value at position $(m,n)$. The value of $d_{XY}(m,n)$ is obtained by applying filter $F^*=[1,-3,4,-3,1]$ along the $m^{th}$ row of the Bayer CFA image as shown in Fig. 2. Filter $F$ is actually a combination of $F_1=[-1,2,-1]/2$ and $F_2=[-1,1,-1]/3$. $F_1$ is for CD estimation while $F_2$ is for noise removal.

The northbound, the westbound and the southbound EIGs of the pixel $(i,j)$ shown in Fig. 1(b) can be defined similarly by rotating the Bayer image clockwise by 90°, 180° and 270° respectively and then computing the eastbound EIGs of the rotated versions with (1). For reference, they are denoted as $\tilde{E}_{ij}^N$, $\tilde{E}_{ij}^W$ and $\tilde{E}_{ij}^S$ respectively.

Due to the absolute value nature of $\tilde{N}_{X,Y}^E(m,n)$ and the fact that $d_{XY}(m,n) = - d_{XY}(m,n)$, we have $\tilde{N}_{X,Y}^E(m,n) = \tilde{N}_{Y,X}^E(m,n)$. Accordingly, the gradient information carried by $\tilde{E}_{ij}^E$, $\tilde{E}_{ij}^W$, $\tilde{E}_{ij}^N$ and $\tilde{E}_{ij}^S$ are all extracted from the same CI and CD planes. This implies that they are all compatible for comparison.

For the case shown in Fig. 1(b), the EIG holds two more CI gradients from the R and B planes as compared with the IG proposed in [8]. This provides more information to detect the edge direction and hence helps to improve the demosaicing performance.

For the pixel $(i,j)$ in cases shown in Figs. 1(a), 1(c) and 1(d), their directional EIGs are defined similarly as above. One can replace the Bayer samples with the corresponding color samples and follow the same procedures as those used for computing the eastbound EIGs of the pixel $(i,j)$ shown in Fig. 1(b).

As for the weighting factor $\alpha$, an empirical study was carried out to investigate its impact to the demosaicing performance. It is found that the proposed algorithm attains the maximum CPSNR at around $\alpha=3.75$. In particular, CPSNR is defined as

$$CPSNR = 10 \log_{10} \left( \frac{3 \times S_I \times 255^2}{\|I_o - I_r\|^2} \right)$$

where $I_o$ and $I_r$ are, respectively, the full-color ground truth image and the demosaicing result, and $S_I$ is the image size.

### III. THE PROPOSED DEMOSAICING ALGORITHM

The proposed demosaicing algorithm exploits the EIGs in various stages to improve the interpolation efficiency. Fig. 3 briefly illustrates the workflow of the proposed demosaicing method. Note that no further enhancement is required for the red and blue planes at the end and hence the enhancement overhead is significantly reduced as compared with other conventional refinement schemes exploited in other demosaicing methods [4-7,9-12].

For reference, hereafter, a pixel at location $(i,j)$ in the Bayer image is represented by either $(R_{ij}, G_{ij}, B_{ij})$, $(r_{ij}, G_{ij}, b_{ij})$ or $(r_{ij}, g_{ij}, b_{ij})$, where $R_{ij}$, $G_{ij}$, and $B_{ij}$ denote the known red, green and blue Bayer samples and $r_{ij}$, $g_{ij}$ and $b_{ij}$ denote the unknown samples of corresponding color channels in the image. The final estimates of $r_{ij}$, $g_{ij}$ and $b_{ij}$ are denoted as $\hat{r}_{ij}$, $\hat{g}_{ij}$ and $\hat{b}_{ij}$ respectively for clear presentation.

#### A. Green Plane Interpolation

As far as a pixel which does not have a green Bayer sample is concerned, the pattern of its local region must be in the form shown in either Figs. 1(c) or 1(d). Without losing generality, the former pattern is discussed in this paper. For the pattern shown in Fig. 1(d), one can exchange the red samples with the corresponding blue samples and then performs the interpolation in the same way.

In the proposed algorithm, instead of the popular Laplacian filter used in various demosaicing algorithms such as [8,13], the accurate high-order interpolator proposed in [14] is used to provide four estimates of a missing green sample as follows.

$$\hat{G}_{ij}^E = \frac{(R_{ij} - r_{ij,z2})}{2} + \frac{(G_{ij,1} - 2G_{ij,3} + G_{ij,5})}{8}$$

$$\hat{G}_{ij}^W = \frac{(R_{ij} - r_{ij,z2})}{2} + \frac{(G_{ij,1} - 2G_{ij,3} + G_{ij,5})}{8}$$

$$\hat{G}_{ij}^N = \frac{(R_{ij} - r_{ij,z2})}{2} + \frac{(G_{ij,1} - 2G_{ij,3} + G_{ij,5})}{8}$$

$$\hat{G}_{ij}^S = \frac{(R_{ij} - r_{ij,z2})}{2} + \frac{(G_{ij,1} - 2G_{ij,3} + G_{ij,5})}{8}$$

where $\hat{G}_{ij}^E$, $\hat{G}_{ij}^W$, $\hat{G}_{ij}^N$ and $\hat{G}_{ij}^S$ are, respectively, the estimates obtained from the east, the west, the north and the south ends with the high-order interpolator.

The four green estimates are then adaptively fused based on the EIGs at pixel $(i,j)$ to provide 3 new green estimates, which are considered as the green estimates obtained by interpolating the missing green component of pixel $(i,j)$ along the horizontal, the vertical and in both directions respectively, as follows.

$$g_{ij}^G = \sum_{k \in \{E,W\}} w_k^E \hat{G}_{ij}^k / \sum_{k \in \{E,W\}} w_k^E$$

Fig. 2 Estimation of color difference values for computing eastbound or westbound EIGs

Fig. 3 Workflow of the proposed demosaicing method
\[ g^r_{i,j} = \sum_{k \in \{N,S\}} w^k \hat{G}_{i,j}^k - \sum_{k \in \{W,N,S\}} w^k, \quad (10) \]
\[ g^d_{i,j} = \sum_{k \in \{E,W,N,S\}} w^k \hat{G}_{i,j}^k - \sum_{k \in \{E,W,N,S\}} w^k, \quad (11) \]

where \( g^H, g^V, \) and \( g^D \) denote, respectively, the three new green estimates of the pixel, and \( w^k = 1/\hat{\sigma}^2_{i,j} \) are the weights of \( \hat{G}_{i,j}^k \). The weighting mechanism in (9)-(11) directs the interpolation automatically when there is an edge.

The selection of interpolation directions is critical to the demosaicing performance. A two-pass estimation scheme as shown in Fig. 4 is used to estimate the missing green samples at a reduced complexity. This scheme produces a preliminary green estimate denoted as \( \hat{g}_{i,j} \) for each pixel \((i, j)\) without a green Bayer sample.

In the first pass of the scheme, the Bayer image is raster scanned. For each pixel which does not have a G Bayer sample as the pixel \((i, j)\) shown in Fig. 1(c) or 1(d), three EIG-based parameters are computed as
\[ \hat{\partial}H = \hat{\alpha}^E_{i,j} + \hat{\alpha}^W_{i,j}, \]
\[ \hat{\partial}V = \hat{\alpha}^N_{i,j} + \hat{\alpha}^S_{i,j} \quad \text{and} \]
\[ E = \max(\hat{\partial}H / \hat{\partial}V, \hat{\partial}V / \hat{\partial}H). \quad (12) \]

The pixel is then classified according to the nature of its local region based on the classification criteria shown in Fig. 4. If the pixel is classified to be in an edge region, it will be processed in Pass 1. Otherwise it will be handled in Pass 2. The threshold \( T \) is studied empirically. Study result shows that the proposed demosaicing method attains a promising result when \( T = 1.9 \).

In Pass 2, for each unprocessed pixel, its CD variation along different directions is re-estimated with the newly added information provided by the green estimates obtained in Pass 1 to select the interpolation direction.

As an example, let us assume that the green sample of pixel \((i,j)\) shown in Fig. 1(c) cannot be determined in Pass 1. In Pass 2, the CD estimates of pixel \((p,q) \in \{(i+j+2), (i+2,j) \mid t=0,1,2,3\}\) are first re-estimated as
\[ \phi^r_{p,q} = \begin{cases} \hat{g}_{p,q} - R_{p,q} & \text{if } \hat{g}_{p,q} \text{ was obtained in pass 1} \\ \hat{g}_{p,q} - R_{p,q} & \text{otherwise} \end{cases} \]
for \( k \in \{H,V,D\}, \quad (13) \)

where \( \phi^H_{p,q}, \phi^V_{p,q} \) and \( \phi^D_{p,q} \) are, respectively, the green-to-red CD estimates of pixel \((p,q)\). They are used to estimate the CD variation along the horizontal, the vertical and the diagonal axes passing pixel \((i,j)\). In particular, the extent of CD variation along the three axes are measured as
\[ \Omega_H = \sum_{t=0}^{3} \left| \phi^H_{i+j+2t} - \phi^H_{i,j} \right|, \quad \Omega_V = \sum_{t=0}^{3} \left| \phi^V_{i+2t,j} - \phi^V_{i,j} \right| \]
and
\[ \Omega_D = \frac{1}{2} \sum_{t=0}^{3} \left| \phi^D_{i+j+2t} - \phi^D_{i,j} \right| + \left| \phi^D_{i+2t,j} - \phi^D_{i,j} \right|. \quad (14) \]

where \( \Gamma = \{0, \pm 1, \pm 2, \pm 3\} \). Based on the three measures, the interpolation direction and the missing green sample of pixel \((i,j)\) can be determined as shown in Fig. 4.

The interpolation direction and the missing green sample of the pixel \((i,j)\) that contains a blue Bayer sample as shown in Fig. 1(d) can be determined similarly by exchanging the roles of red samples and blue samples and then following the same procedures as mentioned above. At the end of Pass 2, a complete demosaiced green plane is obtained.

B. Adaptive Green Plane Enhancement

With the fully populated green plane, the proposed algorithm then refines the demosaiced green samples prior to the interpolation of the red and the blue planes. The refinement is carried out in the CD domain.

For a pixel \((i,j)\) with its neighborhood as shown in Fig. 1(c), the refined green value, \( \tilde{g}_{i,j} \), is attained as
\[ \tilde{g}_{i,j} = R_{i,j} - \tilde{d}_{i,j}, \quad (15) \]
where \( \tilde{d}_{i,j} \) is a refined red-green CD estimate of the pixel. In the proposed algorithm, \( \tilde{d}_{i,j} \) is acquired by fusing two individual red-green CD estimates, \( \tilde{d}_{i,j} \) and \( \tilde{d}_{i,j} \), as
\[ \tilde{d}_{i,j} = \beta \tilde{d}_{i,j} + (1 - \beta) \tilde{d}_{i,j}, \quad (16) \]
where \( \beta = 0.42 \) is an empirical weighting factor controlling the fusion. \( \tilde{d}_{i,j} = R_{i,j} - \tilde{g}_{i,j} \) is the difference between the known red sample \( R_{i,j} \) and the preliminarily demosaiced green sample \( \tilde{g}_{i,j} \), and \( \tilde{d}_{i,j} \) is derived based on \( \tilde{d}_{i,j+2} \) and \( \tilde{d}_{i,j-2} \) as
\[ \tilde{d}_{i,j} = \begin{cases} \frac{w^E \tilde{d}_{i,j+2} + w^W \tilde{d}_{i,j-2}}{w^E + w^W} & \text{if } \text{Dir}_{i,j} = H \\ \frac{w^N \tilde{d}_{i,j+2} + w^S \tilde{d}_{i,j-2}}{w^N + w^S} & \text{if } \text{Dir}_{i,j} = V \\ \frac{w^E \tilde{d}_{i,j+2} + w^W \tilde{d}_{i,j-2} + w^N \tilde{d}_{i,j+2} + w^S \tilde{d}_{i,j-2}}{w^E + w^W + w^N + w^S} & \text{if } \text{Dir}_{i,j} = D \end{cases} \quad (17) \]
where $w_k^k = 1/\partial_{i,j}^k$ for $k \in \{E,W,S,N\}$. Note that $\text{Dir}_{i,j}$ is the interpolation direction of pixel $(i,j)$ and it is obtained during the green plane interpolation. With the interpolation direction as supplementary information to compute $\hat{d}_{i,j}$, better enhanced green estimates can be attained.

Similar procedures can be applied to enhance the demosaiced green samples at pixels carrying blue Bayer samples. At the end of the enhancement, all $\tilde{g}_{i,j}$ are updated and finalized to be $\hat{g}_{i,j}$.

C. Red Plane and Blue Plane Interpolation

Based on the enhanced green plane, the missing red and blue samples are estimated next. Due to the page constraint of the paper, only the interpolation of the red plane is described in this paper. For the blue plane interpolation, it can be carried out similarly by interchanging the roles of the red and blue samples.

For easier interpolation, the missing red samples at the blue sampling positions are estimated first. As shown in Fig. 1(d), there are four known red samples placed around the corners of a pixel that has a blue Bayer sample. The red-green CD values $\hat{d}_{i,j}, j \in \{1,2\}$ of these diagonal neighbors are known as they were computed in the green plane enhancement stage, and hence they can be used to estimate $\hat{d}_{i,j}$, the red-green CD value of pixel $(i,j)$.

In the proposed algorithm, $\hat{d}_{i,j}$ is estimated to be the $\hat{d}_{i,j}$ that minimizes objective function

$$J_1 = \sum_{k \in \{N,S\}, k \in \{E,W\}} (\hat{d}_{i,j} - \hat{d}_{i,j}^{k,k})^2 / \hat{c}_{i,j}^{k,k},$$

where $\hat{d}_{i,j}^{SE} = \hat{d}_{i-1,j+1}$, $\hat{d}_{i,j}^{NW} = \hat{d}_{i-1,j-1}$, $\hat{d}_{i,j}^{SE} = \hat{d}_{i+1,j+1}$ and $\hat{d}_{i,j}^{SW} = \hat{d}_{i+1,j-1}$. $\hat{c}_{i,j}^{k,k}$ is the EIG along a diagonal direction and it is estimated as

$$\hat{c}_{i,j}^{k,k} = \hat{c}_{i,j}^{k,k} + \hat{c}_{i,j}^{k,k}$$

for $k_1 \in \{S,N\}$ and $k_2 \in \{E,W\}$. (19)

Once $\hat{d}_{i,j}$ is determined, the missing red sample of pixel $(i,j)$ is estimated as

$$\hat{r}_{i,j} = \hat{g}_{i,j} + \hat{d}_{i,j}$$

(20)

Now, only the red samples at the green sampling positions are left missing. Suppose that pixel $(i,j)$ is a pixel at the green sampling position of the Bayer image. The missing red sample of the pixel, $r_{i,j}$, can be estimated as

$$\hat{r}_{i,j} = \hat{G}_{i,j} + \hat{d}_{i,j},$$

(21)

where $\hat{d}_{i,j}$ is the red-green CD value of pixel $(i,j)$, the value of which is yet to be estimated. In the proposed method, the value of $\hat{d}_{i,j}$ is estimated to be the $\hat{d}_{i,j}$ that minimizes objective function

$$J_2 = \sum_{k \in \{E,W,S,N\}} (\hat{d}_{i,j} - \hat{d}_{i,j}^{k,k})^2 / \hat{c}_{i,j}^{k,k},$$

where $\hat{d}_{i,j}^{k,k}$ are the red-green CD values of the four-connected neighbors of pixel $(i,j)$ and $k \in \{E,W,N,S\}$ specifies which side the referred neighbor is on. Note that $\hat{d}_{i,j}^{k,k}$ are all known at this stage as they were estimated either when enhancing the green plane or when interpolating the missing red samples at the blue sampling positions.

The red plane interpolation completes once all missing red samples are computed. The blue plane interpolation can be carried out in the same way by exchanging the roles of the red and the blue samples. At last, a complete demosaiced full color image can be achieved.

IV. SIMULATION RESULT

The proposed method was compared with ten state-of-the-art demosaicing methods including AP [15], AF [16], LMMSE [17], AHDA [4], VCD [5], DFD [6], HPHD [7], RAD [18], SSD [19] and (IGD) [8] to evaluate its performance. Twenty-four digital full color images as shown in Fig. 5 were used in the simulations. These full color images were first sub-sampled according to the Bayer pattern to form a set of testing Bayer images. They were then reconstructed to full color images with various demosaicing methods for comparison. For fair comparison, whenever there is a refinement scheme recommended by the authors of a particular demosaicing method to enhance its demosaicing results, the scheme was performed in the simulation as suggested. Table I tabulates the CPSNR and the S-CIELAB [20] measures of various demosaicing methods. The proposed algorithm provides the best performance in terms of both measures.

Fig. 6 shows part of the demosaicing results of image 22 for visual comparison. It can be observed that, even though the image contains high-contrast and complicated structures like the fine window frame of the attic, the proposed algorithm can still preserve the structure details and produce results with the least visual artifacts among the evaluated methods including IGD. These results demonstrate that the proposed EIG is more reliable than the integrated gradient and can provide more accurate gradient information for edge detection even in complex regions.

Fig. 5 Twenty-four full color testing images, referring to image 1 to image 24 in a raster scanning
Table II shows the average PSNR performance of various decision-based demosaicing methods in interpolating the green plane. Ours-LI is a variant of the proposed method in which the directional Laplacian interpolator [13] instead of the high-order interpolator proposed in [14] is used to interpolate the green plane. For fair comparison, no enhancement step is applied here to refine the green samples produced by the evaluated methods. One can see that the proposed demosaicing method reproduces the best green plane in terms of PSNR no matter which interpolator is used. It implies that the proposed EIG is effective and provides more edge information for one to interpolate the missing pixel samples across the edges.

For studying the contribution of the EIG to the red and the blue plane interpolation, Table III shows the average PSNR performance of the red and the blue planes attained by various interpolation schemes. In this simulation, the green plane obtained by the proposed demosaicing method (with green plane enhancement) is used as a reference for the bilinear, a hue-based [2], an edge-based [6] and our EIG-based schemes to reproduce their red and blue planes for fair comparison. The simulation results reveal that the proposed EIG can effectively improve the quality of the red and the blue planes.

A study on the contribution of the proposed EIG-based green plane enhancement to the overall demosaicing performance shows that the enhancement step can boost up the quality of the red, the green and the blue planes by 0.39, 1.34 and 0.45 dB respectively in terms of PSNR on average. Note that no explicit enhancement on the red and the blue planes is carried out. Their enhancement is achieved by the green plane enhancement indirectly.

In our simulations, the proposed demosaicing method takes around 99 arithmetic operations to handle a pixel on average, and the average execution time required to process a Bayer image of size 768×512 on a Xeon 3.0GHz workstation with 2GB RAM is around 0.078s.

V. CONCLUSION

In this paper, an efficient decision-based demosaicing method is presented. An enhanced edge-sensing measure called enhanced integrated gradient (EIG) is exploited in various stages to guide the interpolation along edges. This measure improves the previously proposed integrated gradient by including more gradient information from various color planes and hence can provide more reliable information for one to interpolate the missing samples in a Bayer image along the edges. As this enhanced measure is directionally compatible, when it is applied to estimate the missing samples, not only the interpolation direction in different color channels are promised to be coherent, the computation effort required to repeatedly extract gradient information from intermediate interpolation results can also be saved. An EIG-based green plane enhancement which refines the demosaiced green samples before the interpolation of the red and the blue planes is also proposed to further improve the efficiency of the proposed method. Simulation results revealed that the proposed EIG is reliable and the proposed demosaicing method outperforms the up-to-date demosaicing methods both objectively and subjectively at a low computational cost.

REFERENCES

Table I  Performance of various demosaicing methods

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<tr>
<th>Method</th>
<th>AP</th>
<th>AF</th>
<th>LMMSE</th>
<th>AHDA</th>
<th>VCD</th>
<th>DFPD</th>
<th>HPHD</th>
<th>RAD</th>
<th>SSD</th>
<th>IGD</th>
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<tr>
<td>CPSNR</td>
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<td>S-CIELAB</td>
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Table II  Performance of various decision-based demosaicing methods in green plane interpolation

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<th>DFPD</th>
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<th>IGD</th>
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<th>Ours</th>
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<td>PSNR of the G plane (in dB)</td>
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<td>39.64</td>
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<td>40.16</td>
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Table III  Average PSNR performance (in dB) of various red/blue plane interpolation schemes

<table>
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<td>PSNR of the R plane</td>
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<td>PSNR of the B plane</td>
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<td>38.82</td>
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Fig. 6  Part of the demosaicing results of image 22 obtained with various demosaicing methods