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Review on Demosaicking via Directional Linear Minimum Mean Square Error Estimation

Nidhi Chauhan[1], Shanu Sharma[2]
[1, 2] Computer Science Department, Amity University, Noida

Abstract: *The digital cameras test scenes utilize a color channel cluster of mosaic example (e.g., the Bayer example). The demosaicking of the color samples in [4] is basic to the picture essence. It displays another shading demosaicking procedure of ideal directional sifting of the green- red and green-blue contrast signals. Expecting it that the essential distinction signals (PDS) between the green and the red/blue channels are low pass, the missing green samples are robustly decided in both even and additionally vertical bearing by the direct least mean square-mistake estimation (LMMSE) procedure. These directional evaluations will be then ideally intertwined to further enhance the green gauges. In conclusion, guided by the demosaicked full-determination green channel, the other two shading channels are recreated from the LMMSE separated and intertwined PDS.*

Keywords: Color Demosaicking, Bayer color filter array (CFA), directional filtering, linear minimum mean square-error estimation (LMMSE).

I. INTRODUCTION

Demosaicking is a technique used to find the value of each pixel of interpolated image. Today we found that the digital cameras resolutions are more and more but the logic is same. Color filter array (CFA) is used in the digital cameras sample scenes (eg: Bayer Pattern). Image quality is more concern with the demoaicking of color samples. New technique of color demosaicking i.e. Directional Linear Minimum Mean Square Error Estimation is used to determine the color samples with the difference of green - red and green - blue samples. Directional Linear Minimum Mean Square Error Estimation (DLMMSE) technique is used to evaluate primary difference signals (PDS) between green and red/blue channels in horizontal as well as vertical directions. These estimations are further used to enhance the value of the green channel by fusing together. At the end both the red and the blue are calculated by demosaicked full resolution green channel estimated above. By performing this method we found the PSNR and the visual perception to be more accurate [10]. If we consider there is a square grid in which red, blue and green color are arranged in such a manner that each square of four pixels has on red , one blue and two green filter as shown in Figure 1. It is because our eye is more perceptive to green color as compared to red or blue. There are many different techniques to measure Peak Signal to Noise Ratio (PSNR). Few of them are Pixel Doubling Interpolation, Bilinear Interpolation, Gradient Based Interpolation and High Quality Linear Interpolation. J. E. Adams et al [3] describes basic methods which can be used in for demosaicking explained with advantages and disadvantages of individuals. The four methods explained in these papers are pixel doubling interpolation, bilinear interpolation, gradient based interpolation and high

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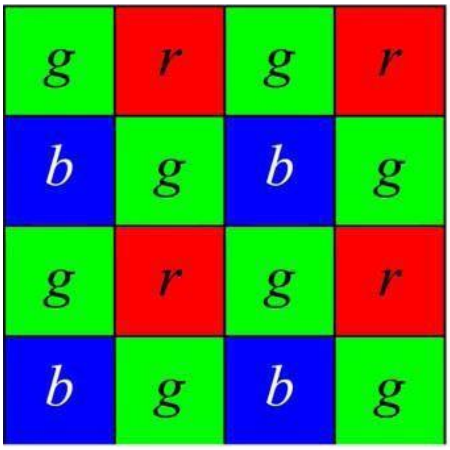

Figure 1: Bayer Pattern

quality linear interpolation. All these techniques use a simple Bayer pattern color filter array.B. K. Gunturk, Y. Altunbasak and R. M. Mersereau et al [7] explains the advanced cameras utilization color channel clusters to test red, green, and blue hues as per a particular sample. At the place of every pixel one and only coloring specimen is taken, and the estimations of the other hues must be interjected utilizing neighboring tests. This shading plane interjection is known as demosaicking; it is one of the critical undertakings in a computerized camera pipeline Many digital cameras uses single sensor array which is used to capture an image. On every pixel, stand out of the three essential hues (red, green and blue) is examined. Here we are utilizing Bayer color filter array (CFA). To reproduce a full color picture the missing shading examples need to be interjected by a procedure called color demosaicking. The nature of these reproduced color pictures relies on the picture substance and the demosaicking strategy we are utilizing.

Previously we have used the nearest neighbor techniques, bilinear interpose and couple of other different methods to demosaicked the image. Those methods were easily used and therefore suffer from some problems like blurring, blocking and zipper effect at the edges. The smooth hue transition (SHT) methods interpose the luminance channel i.e. green and chrominance channels i.e. red and blue. After we get the green channel by bilinear interpolation, we get the red and blue channels by bi-linearly interposing the red hue (the ratio of red to green) and blue hue (the ratio of blue to green). Although the SHT methods have the interrelation between the red, the blue and the green channels, they will result in large interpolation errors in red and blue channels when green values unexpectedly modified.

Many demosaicking methods avoid interpolating at edges, as human visual systems are very perceptive to the edge organization in an image. At each pixel the gradient is calculated, and the color interpolation is done by using directionally based on the determined gradient. Directional filtering is very prominent way for color demosaicking that gives competing results. The best known directional interpolation scheme is the second order Laplacian filter [2]. When the green examples are filled in the picture, then after the red and the blue specimens are interjected comparably with the rectification of the second request slopes of the green channel. One more slope based demosaicking system displayed by Chang et al [7] is utilized as a situated of slopes in diverse bearings in the 5x5 area focused at the pixel to be interjected. A subset of the arrangement of these slopes is chosen by versatile limit. Another type of color demosaicking techniques is iterative method, which we can also be used with the gradient-based methods. Iterative demosaicking process consist of two-step i.e. of an enhancement step and a reconstruction step [13]. Based on its eight neighbors, we calculate eight directional derivatives at each pixel . Another iterative demosaicking strategy was given by Gunturk [7]. Investigating the way that the three color channels of a characteristic picture are profoundly connected. Firstly the picture is inserted by utilizing Bilinear or other demosaicking routines, and afterward green channel is upgraded by the high recurrence data of red and blue channels. Finally a wavelet based iterative procedure was utilized to upgrade the high recurrence points of interest of the red and blue channels as indicated by the green channel.

In all sort of color demosaicking strategies inclination examination plays an essential or we can say a focal part in reproducing sharp edges. On the other hand, the inclination estimation may not be hearty when the info sign surpasses the Nyquist recurrence. This demonstrates that the fundamental driver of shading relics in demosaicked pictures [4]. A typical proceeding in color demosaicking is to endeavor the relationship between the color channels. As we realize that the three shading channels for a characteristic picture are very interrelated, the distinction between the green channel and the red or blue channel constitutes a smooth (low-pass) process. Besides, we watch that this shading distinction sign is not related to the interjection slips of inclination guided shading demosaicking routines, which is essentially band-pass process.

II. MINIMUM MEAN SQUARE ERROR

These considerations provide a principle for calculating the color difference signals by minimum mean square-error determination method [11], which provides a good approximation to the optimal determination in mean square-error. The minimum mean square-error determination are obtained in both vertical as well as horizontal direction, and then fused optimally to remove the demosaicking

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noise. At the end, the full resolution for three color channels are rebuilt from the minimum mean square-error determination filtered difference signals. The practical results proves that this new color demosaicking technique gives better improvement both in PSNR measure and visual perception. This technique is basically used for Bayer pattern which is mostly found everywhere, but it can be elongated for other CFA patterns also [5]. To take an favor of spectral interrelations, we calculated the red-green and the blue-green difference images, called primary difference signals (PDSPDS), instead of precisely getting the missing color samples.

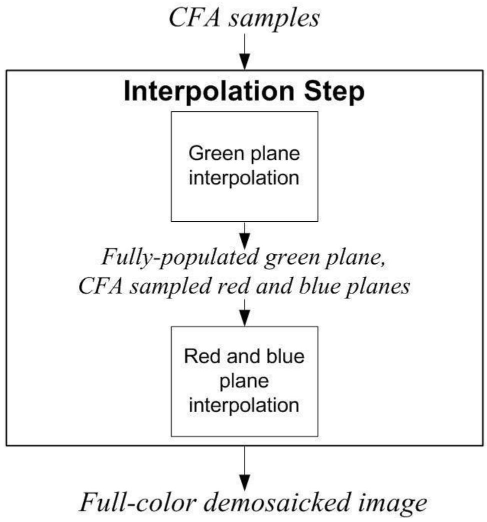

Figure 2: Algorithm for demosaicking

A linear model as shown in Figure 2 is used to show and calculate the red-green and the blue-green PDS signals. Observed PDS values are showed as the sum of color interpolation error (IE) and true PDS. Based on the second order measurements of these components, a minimum mean square error detection method is used to calculate the PDS from the strident measurements. From the calculated PDS, we determined a full resolution green image. The red and the blue channels are then after recovered.

III. PRIMARY DIFFERENCE SIGNAL AND DIRECTIONAL DEMOSAICKING NOISE

To estimate high-frequency countenance ahead the Nyquist frequency of Color Filter Array, a color demosaicking scheme depends on some additional properties for the input color signals. A very common property is the interrelation between the sampled primary color channels: i.e. the red, the green, and the blue. To exploit this property in demosaicking method, let us find the relationships between the green and the red channels, and between the green and the blue channels. There are number of reasons why the green channel has a major role in our determination of omitted color samples. Firstly, the green channel has double of the total samples as the other two channels in the Bayer mosaic pattern. Secondly, the perceptiveness of the human eye at the green wavelength. Thirdly, the green channel is close to the red and to the blue than the difference between the red and the blue in wavelengths [6]. We assume that the difference images between the green and the red channels and between the green and the blue channels are low-pass signals, that are referred one after the other as primary difference signals (PDS) and are denoted by

$$\Delta g\,,\ r(n) = Gn - Rn$$
$$\Delta, b(n) = Gn - Bn$$

Where n is known as the position index of the pixel.

We calculate PDS Δg,r and Δg ,b instead of particular color channels directly because random processes Δg ,r and Δg ,b have some statistical properties that can be extracted for demosaicking. We are interested in how the demosaicking noise relates to Δg ,r and Δg ,b. The most effective color demosaicking filters is the second-order directional Laplacian filter which is depends on a robust basis that Δg ,r and Δg ,b are constant in either horizontal direction or vertical direction. The major question is that which Interpolation heading is to be chosen

Using the interpolated missing green and red values, we obtain two conclusion of the arbitrary mechanism *Delta* g, r in horizontal and vertical directions as shown in Figure 3, respectively

IΔhg, r (i) = IG hi - R hi , G is interpolated

as opposed to settling on a brutal choice, we can make two different determinations of a missing essential shading specimen in level and vertical bearings, and afterward consolidating the two determinations.

We have seen the design of the Bayer sample. A section and a column of exchanging green and red specimens cross at a red inspecting location, where the missing green quality is to be resolved. Correspondingly we go for blue channel too. Similarly we go for blue channel also. We denote the red sample at the center of the window as $R0$. Its interlaced red and green neighbors in horizontal

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direction are labeled as $Rh\ i$, i²…,-4,-2,2,4 and $Gh\ i$, i ² …,-3,-1,1,3 respectively; similarly, the red and green neighbors of $R0$ in vertical direction are $Rh0$, and Rvi.

To get some coarse dimensions of PDS Δg,r and Δg,b, we first interpose the omitted green samples at red and blue pixels and then interpose the missing red and blue samples at green samples. Any of the prevailed interpolation methods for color demosaicking may be used.

For any red original sample Rhi or Rhj, the corresponding omitted green sample is interpolated as

$$IG_{hi} = 1/2\ (G_{hi-1} + G_{hi+1}) + 1/4\ (2.\ R_{hi} - R_{hi-2} - R_{hi+2})$$
$$IG_{vj} = 1/2\ (G_{vj-1} + G_{vj+1}) + 1/4\ (2.\ R_{vj} - R_{vj-2} - R_{vj+2})$$

Similarly, for any original green sample Ghi or Gvj, the corresponding missing red sample is interpolated as

$$IR_{hi} = 1/2\ (R_{hi-1} + R_{hi+1}) + 1/4\ (2.\ G_{hi} - G_{hi-2} - G_{hi+2})$$
$$IR_{vj} = 1/2\ (R_{vj-1} + R_{vj+1}) + 1/4\ (2.\ G_{vj} - G_{vj-2} - G_{vj+2})$$

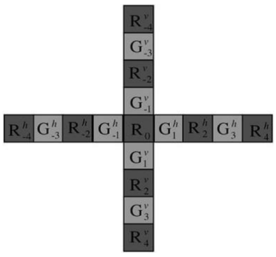

Figure 3:Row and column of mosaic data that intersect at red sample position.

$$= G\ hi - IR\ hi\ ,\ R \text{ is interpolated}$$
and
$$I\Delta vg,\ r\ (i) = IG\ vi - R\ vi\ ,\ G \text{ is interpolated}$$
$$= G\ vi - IR\ vi\ ,\ R \text{ is interpolated}$$

The measurement errors associated with $I\Delta_{hg,\ r}$ and $I\Delta_{vg,\ r}$ are

$$E_{hg,\ r} = \Delta_{g,\ r} - I\Delta_{hg,\ r}$$
$$E_{vg,\ r} = \Delta_{g,\ r} - I\Delta_{vg,\ r}\ .$$

We regard $I\Delta_{hg,\ r}$ and $I\Delta_{vg,\ r}$ to be two observations of $\Delta_{g,\ r}$ and, accordingly, $E_{hg,\ r}$ and $E_{vg,\ r}$ to be the correlative directional demosaicking noises, and rewrite and as

$$I\Delta_{hg,\ r} = \Delta_{g,\ r} - E_{hg,\ r}$$
$$I\Delta_{vg,\ r} = \Delta_{g,\ r} - E_{vg,\ r}$$

Now, the we have to find an optimal estimate of Δg,r from the two observation sequences $I\Delta_{hg,\ r}$ and $I\Delta_{vg,\ r}$, and then acquire the omitted green values The evaluated algorithm will be developed in the next step.

To abridge the notations, we express by x the true PDS signal Δg ,r and by y the linked observation $I\ \Delta h$,r or $I\ \Delta v$,r and by v, the linked demosaicking noise $E_{hg,r}$ or $E_{vg,r}$ namely

$$y(n) = x(n) + v(n)$$

The optimal minimum mean square-error estimation (MMSE) of x is

nd $E_{vg,\ r}$.

IV. INTERPOLATION OF OMITTED RED (BLUE) SAMPLES AT THE BLUE (RED) SAMPLE LOCATIONS

We firstly interpolate the omitted red sample at a blue pixel B_n. R_{nnw} , R_{nsw}, R_{nne}, R_{nse} are the four nearest red neighbors of the blue sample position B_n, where the superscripts are directional notations for northwestern, southwestern northeastern and southeastern.Note that R_{nnw} , R_{nsw} , R_{nne} , R_{nse} and B_n are all original samples in the Bayer Pattern. The calculated green samples at these locations are expressed by

$G1nwn$, $G1swn$,$G1nen$, G1sen , G1n respectively as shown in Figure5.

At that point, the omitted red specimen is assessed as

$$R1n = G1n - \Delta n,\ gr$$

Thus the missing blue samples at red sample positions R_n can be interjected. The four green-blue distinction values in the northwestern, southwestern, northeastern and southeastern of R_n are accessible.

$$x1 = M[x/y] = \int xp(x/y)dx$$

Then again, the MMSE estimation is extremely extreme, if conceivable by any means, on the grounds that p(x/y) is sometimes known practically speaking. Rather, we utilize the LMMSE strategy to gauge x from y, which is a decent estimate to MMSE however more

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manageable to proficient usage. Especially, if x(n) and v(n) are provincially Gaussian forms (a sensible supposition for normal picture signals), then The LMMSE of x is computed as

$$x = M[x] + cov(x,y)/var(y)*(y-M[y])$$

we examine that the demosaicking noises $E_{hg,r}$ and $E_{vg,r}$ are zero-mean random processes, and they are almost uncrated with $\Delta_{g,r}$. Consequently, we can simplify the above equation to

$$x1 = \mu_x + \{S_x{}^\wedge 2/(S_x{}^\wedge 2+ S_y{}^\wedge 2)*(y- \mu_x)$$

Where $\mu_x = M[x]$, $S_x{}^\wedge 2 = Var(x)$, $S_y{}^\wedge 2 = Var(y)$.

Uniformly, we can characterize the difference signal Δg,b between the green and blue and its two assessments $I\Delta_{hg,b}$ and $I\Delta_{vg,b}$, in horizontal and vertical directions. The *n* relating estimation lapses $E_{hg,b}$ and $E_{vg,b}$ have the same means as those of $E_{hg,r}$ a

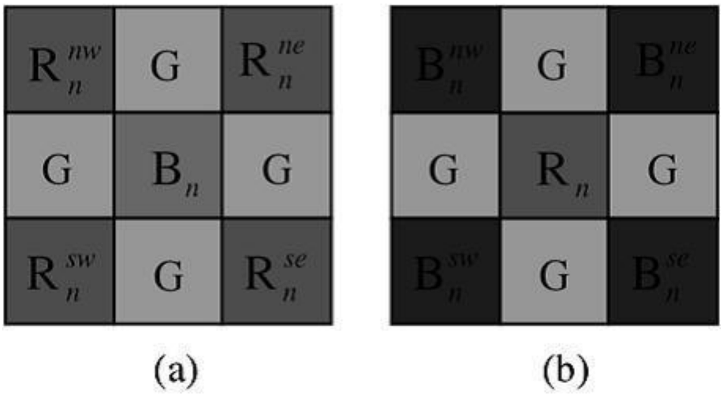

Figure 5: (a) Blue sample and its four nearest red neighbors. (b) Red sample and its four nearest blue neighbors

V. INTERPOLATION OF OMITTED RED/BLUE SAMPLES AT THE GREEN SAMPLE LOCATIONS

When the omitted red/blue samples at the blue/red positions are filled, we come across at the four cases. As earlier, the samples are calculated ones if marked with 1 and original ones otherwise. Because of the uniformity between the red and the blue samples in these four cases, we only need to discuss case (1). Given the green assessments $G1_{nn}$, $G1_{sn}$, $G1_{en}$ and $G1_{wn}$ at the positions $R1_{nn}$, $R1_{sn}$, $R1_{en}$ and $R1_{wn}$ we have the related four green–red difference values, denoted by $\Delta_{nn,gr}$, $\Delta_{sn,gr}$, $\Delta_{en,gr}$, and $\Delta_{wn,gr}$ shown in

Figure 6. As in the preceding step, we calculate the bilinear

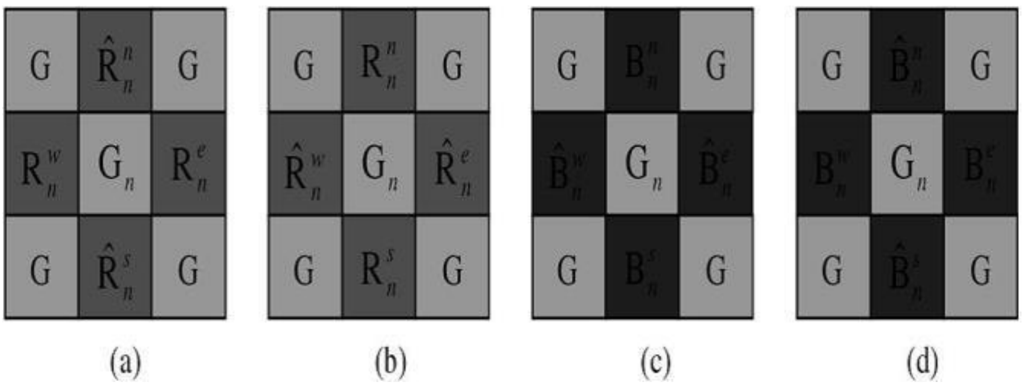

Figure 6: (a)(b) Green sample and its two original and two estimated red neighbors. (c)(d) Green sample and its two original and two estimated blue neighbors

$$\Delta_{n,gr} = (\Delta_{nn,gr} + \Delta_{sn,gr} + \Delta_{en,gr} + \Delta_{wn,gr}) / 4$$

Then, the omitted red sample at green sample position G_n is estimated to be

$$R1n = G1n - \Delta n,gr$$

Likely, the omitted blue sample at a green position is estimated as

$$B1n = G1n - \Delta n, gb$$

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All the omitted red and blue samples have been filled till now. The full color picture is remade. The exhibited demosaicking plan first adventures the relationship between the green and red/blue channels to acquire great appraisals of the omitted green specimens and then gauges the missing red and blue average of the green-red differences [8]. tests by a basic and quick bilinear normal operation on the green-red and green-blue PDS signals [11].

VI. EXPERIMENTAL RESULTS

We implemented the proposed LMMSE color demosaicking algorithm, and tested it on a large number of natural color images. In this section, we present our experimental results for the three images in Fig. 7 shown below, and compare them with the methods of Hamilton *et al.* [11], Chang *et al.* [7], and Gunturk *et al.* [9], which are among the best schemes. The results reported in the recent paper of [9] were better than the previously published algorithms, especially for the red and blue channels. Table I below shows the PSNR values of the tested images. The proposed LMMSE-based demosaicking algorithm appears to produce visually more pleasant color images with color artifacts greatly suppressed.

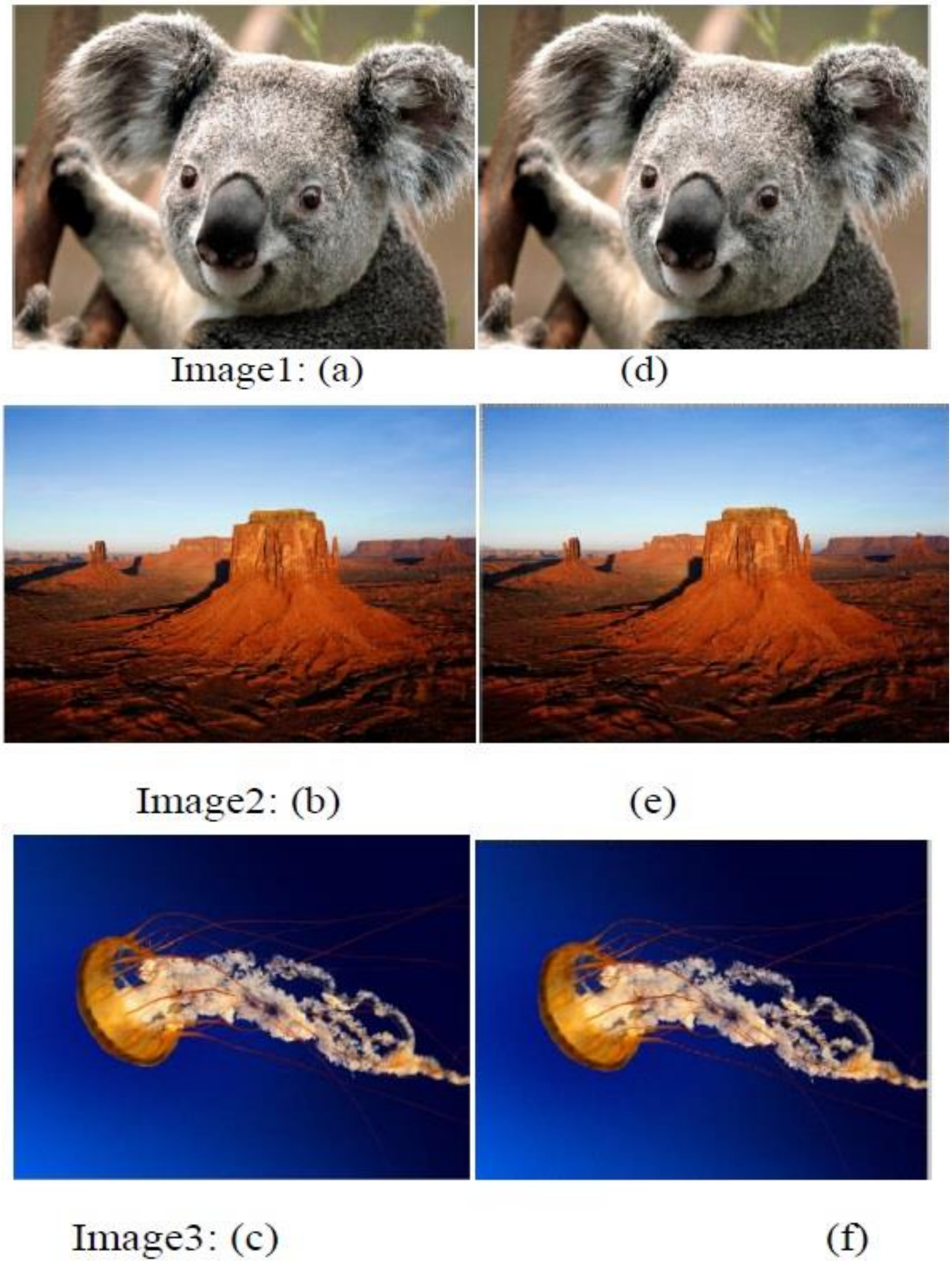

Figure 7: Image (a)-(c) input and (d)-(f) are output

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Table I: PSNR of Tested images

IMAGE NO.	PSNR FOR RED CHANNEL	PSNR FOR GREEN CHANNEL	PSNR FOR BLUE CHANNEL
1	40.47	41.31	37.39
2	42.90	43.33	40.06
3	43.01	44.40	41.90

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