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# Adaptive Weighted Color Interpolation from Noisy Single Sensor Digital Camera Images

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**Abstract:** In this study, a novel adaptive edge preserving, edge directed interpolating technique is proposed for color reproduction from Bayer mosaic images along with a nonlinear filter is proposed for removing the impulse noise. In which, the noisy pixels are replaced with the suitable neighboring minimum difference pixel value. Depending on the sharpness of image, the adaptive weighting technique is introduced for interpolation. Experimental results show that the proposed method performs much better than other latest joint denoising and demosaicing techniques in terms of color peak signal to noise ratio.

**Key words:** Noise removal, impulse noise, interpolation, color filter array

## INTRODUCTION

Nowadays, embedded digital imaging devices have become popular and prevailing over the traditional film cameras. Low cost, low power consumption, miniaturization in size and high speed in operation are demanded from these devices. These devices have been widely embedded in consumer electronics ranging from the conventional digital cameras, mobile phones and imaging devices for automotive and surveillance applications. Commonly, Charge Coupled Device (CCD) or Complementary Metal Oxide Semiconductor (CMOS) sensors are used to capture the image in digital cameras. A representation of a full-color image needs all the information from the three colors on each pixel location. A camera would need three separate sensors to completely capture the image. In a three-chip color camera, the light entering into the camera is split and projected on to each spectral sensor. Each sensor requires its proper driving electronics and the sensors have to be registered precisely. These additional requirements add a large expense to the system. To reduce the hardware cost and size, many digital still cameras use a single mosaiced sensor array to capture any one of the three primary colors at each pixel location. A mosaiced sensor is a monolithic array of many sensors, in which each sensor is covered by an optical filter sensitive to a specified wavelength, arranged in a geometric pattern. Among the various suggested CFAs, the Bayer CFA pattern is the most prevalent one, where G pixels occupy half of all and R and B pixels share the others. As a result, the missing two colors on each pixel location have to be interpolated back to get a full-color image. The process of interpolating the missing colors is called as demosaicing or color interpolation whose main objective aims to reconstruct the missing colors as closely to the original ones as possible (Zhang and Xiaolin, 2005). The output image of a digital camera is subject to a severe degradation due to noise in the image sensor. A typical digital camera is subject to basically two types of noise namely thermal noise and impulse noise (Hirakawa and Parks, 2006). The impulse noise is also called as salt and pepper in images and popcorn noise in audio signals. They are mainly caused due to short impulses of electromagnetic pulses caused from automobile ignition or from chokes of fluorescent tube lights. The impulse noise is destructive one, which changes the pixel value to either zero or maximum. If the value is changed to zero then it is called pepper and if it is changed to 255 then it is called salt. In a RGB color plane, this noise is reflected in all the color planes. Most of the edges will be blurred while applying normal filtering. The proposed method avoids these problems and removes the noise by an iterative error reduction method. Once the noise level is effectively reduced then the image has to be reconstructed from the mosaic image to a color image.

In this study, a novel adaptive weighted color interpolation algorithm using variance of color differences is also proposed. This algorithm aims to estimate the optimum weight value according to edge level to interpolate effectively (Nai-Xiang *et al*., 2007). So that, the proposed algorithm performs superbly both in textured and edge regions.

## NON- LINEAR FILTERING

A Non Linear filtering is presented for the noise reduction of images corrupted with salt and pepper noise.

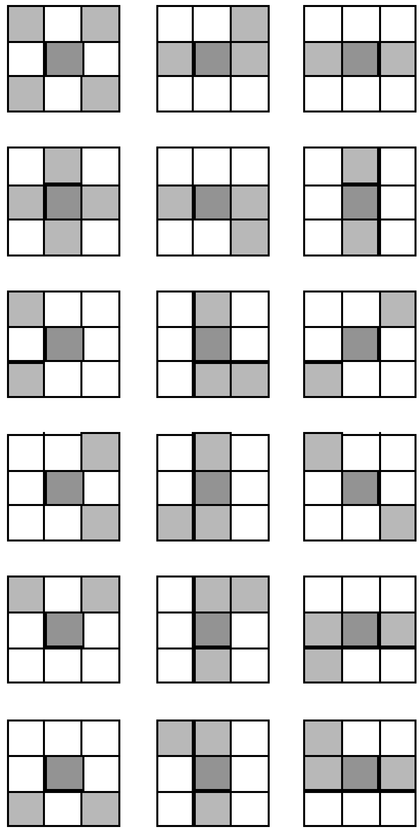

Fig. 1: Edge pixels

This filtering approach consists of two steps. The first step computes the difference matrix for the corrupted image in eight different directions. The second step replaces the noisy pixel's value with the suitable neighbor's value whose difference is a minimum value (Krishnan *et al*., 2007). This study proposes a new approach to detect the corrupted pixel and replace it by the best neighbor pixel value with in the window. The best neighbor is computed from the 8 neighbors, which has minimum number of difference among its 8 neighbors. This approach is used to recover images highly corrupted by salt and pepper noise. This method also preserves the edge details. Impulsive noise and edges have common properties of having abrupt changes in gray level. Therefore, it is important to distinguish noise components from edge components for effective noise filtering and edge preservation. Impulsive noise is defined in a narrow sense as a noise that abruptly changes gray level of a pixel to 0 or 255 in 8-bit monochrome (mosaic) image and in a broad sense as a noise that is conspicuous against neighbor pixels. Luminance value will mainly affect by green pixels. So in this study, impulse noise on green pixels only considered. Impulse noise and edges have common properties of having abrupt changes in pixel level. Identifying noise components from edge components will play an important role while effectively removing noise by preserving edges.

Edge pixels can be distinguished with the help of edge templates from corrupted pixels. Edge templates in a 3×3 window can be generally represented as shown in the Fig. 1. In other words edges generally have more than three similar pixels in the 3×3 window but impulsive noise does not. For the corrupted pixels, all absolute differences with its neighborhood are calculated. Number of absolute differences having value less than half of median of image is counted for each neighborhood pixels. The pixel value of neighborhood having minimum number of absolute differences is filled in the corrupted pixel location.

## ADAPTIVE WEIGHTED

**Demosaicing:** To reconstruct a full-color image from CFA samples, the two missing color values at each pixel are to be estimated from neighboring CFA samples. The green plane is estimated first and the other color planes are estimated based on the interpolated value of the green plane (Chi *et al*., 2006). When the green plane is processed, for each missing green component in the CFA, the algorithm performs a gradient test, to identify edge direction and then carries out an interpolation along the direction of a smaller gradient to determine the missing green component (Kehtarnavaz, 2003).

**Interpolating missing green values:** The parameters $L^H$ and $L^V$ are computed using spatial and spectral correlations using Eq. 1 and 2 as in Chung and Chan (2006). The leading edge direction is determined by computing the ratio of above parameters. If the ratio, e = max ($L^V/L^H$, $L^H/L^V$) is above the pre-determined threshold value then it is defined as sharp edge block. The missing green value of the sharp edge

$$L^H = \sum_{n=\pm2}\left[\sum_{m=0,\pm2}|R_{i+m,j+n}-R_{i+m,j}|+\sum_{m=\pm1}|G_{i+m,j+n}-G_{i+m,j}|\right]+ \sum_{n=\pm1}\left[\sum_{m=0,\pm2}|G_{i+m,j+n}-R_{i+m,j}|+\sum_{m=\pm1}|B_{i+m,j+n}-G_{i+m,j}|\right] \quad (1)$$

$$L^V = \sum_{m=\pm2}\left[\sum_{n=0,\pm2}|R_{i+m,j+n}-R_{i,j+n}|+\sum_{n=\pm1}|G_{i+m,j+n}-G_{i,j+n}|\right]+ \sum_{m=\pm1}\left[\sum_{n=0,\pm2}|G_{i+m,j+n}-R_{i,j+n}|+\sum_{n=\pm1}|B_{i+m,j+n}-G_{i,j+n}|\right] \quad (2)$$

block is computed as follows:

if $L^H<L^V$

$$g(x,y) = Sw(f^H(x,y)) + (1-Sw)(f^V(x,y))$$

if $L^H<L^V$

$$g(x,y) = Sw(f^V(x,y)) + (1-Sw)(f^H(x,y)$$

Where:

$$f^V = g_{i,j} = \frac{(G_{i,j-1}+G_{i,j+1})}{2} + \frac{(2R_{i,j}-R_{i,j-2}-R_{i,j+2})}{4}$$

$$f^H = g_{i,j} = \frac{(G_{i-1,j}+G_{i+1,j})}{2} + \frac{(2R_{i,j}-R_{i-2,j}-R_{i+2,j})}{4}$$

The ratio of total number of edges to total edges having edge value between one and two is referred as edge ratio. If the value of edge is greater than edge ratio, then weight of sharp transition (Sw) is calculated using the ratio of color differences.

| | | |
|---|---|---|
| | $G^V_1$ | |
| $G^H_1$ | R | $G^H_2$ |
| | $G^V_1$ | |

if $L^H < L^V$

$$SW = \frac{(R-G_1^H)(R-G_2^H)}{(R-G_1^V)(R-G_2^V)}$$

if $L^H > L^V$

$$SW = \frac{(R-G_1^V)(R-G_2^V)}{(R-G_1^H)(R-G_2^H)}$$

For regions that are not classified as edge block, a flat region or a pattern region exists and in a local region of a natural image, the color differences of pixels are more or less the same (Daniele, 2007). Accordingly, the variance of color differences can be used to determine the interpolation direction for the green components. The variances of the color differences of the pixels is computed in a 9×9 block window, along horizontal axis, vertical axis and diagonal pixels and are represented as, $H\sigma^2_{i,j}$, $V\sigma^2_{i,j}$ and $B\sigma^2_{i,j}$ respectively. The missing green value can be estimated using Eq. 3, 4 and 5 as (Chung and Chan, 2006).

if $H\sigma^2_{i,j} = \min(H\sigma^2_{i,j}, V\sigma^2_{i,j}, B\sigma^2_{i,j})$ then

$$g_{i,j} = \frac{(G_{i,j-1}+G_{i,j+1})}{2} + \frac{(2R_{i,j}-R_{i,j-2}-R_{i,j+2})}{4} \quad (3)$$

if $V\sigma^2_{i,j} = \min(H\sigma^2_{i,j}, V\sigma^2_{i,j}, B\sigma^2_{i,j})$ then

$$g_{i,j} = \frac{(G_{i-1,j}+G_{i+1,j})}{2} + \frac{(2R_{i,j}-R_{i-2,j}-R_{i+2,j})}{4} \quad (4)$$

$$g_{i,j} = \frac{(G_{i-1,j}+G_{i+1,j}+G_{i,j-1}+G_{i,j+1})}{4} + \frac{(4R_{i,j}-R_{i-2,j}-R_{i+2,j}-R_{i,j-2}-R_{i,j+2})}{8} \quad (5)$$

For estimating the missing green component at blue pixel position, the red samples by the corresponding blue samples and follow the procedures above to determine its interpolation direction and its interpolated value (Xin, 2005).

**Interpolating missing red and blue values at green positions:** The missing red and blue values at green CFA sampling positions are estimated using the Eq. 6 and 7.

Red value interpolation

$$\tilde{R}_{i,j} = G_{i,j} + \frac{R_{i,j-1} - \tilde{G}_{i,j-1} + R_{i,j+1} - \tilde{G}_{i,j+1}}{2} \quad (6)$$

Blue value interpolation

$$\tilde{B}_{i,j} = G_{i,j} + \frac{B_{i-1,j} - \tilde{G}_{i-1,j} + B_{i+1,j} - \tilde{G}_{i+1,j}}{2} \quad (7)$$

**Interpolating missing blue/red values at red/blue positions:** The missing blue (red) values at the red (blue) positions are estimated as follows:

$$\tilde{B}_{i,j} = \tilde{G}_{i,j} + \frac{1}{4}\sum_{m=\pm}\sum_{n=\pm 1}\left(B_{i+m,j+n} - \tilde{G}_{i+m,j+n}\right) \quad (8)$$

## SIMULATION RESULTS

To evaluate the performance of the proposed iterative non linear filtering with adaptive weighted demosaicing method, simulation was carried out with twelve 24 bit digital color images listed in (Table 1). Figure 2 shows the

Fig. 2: Set of tested images (images are numbered from 1 to 12 in the order of left-to-right and top-to-bottom

Table 1: CPSNR in dB comparisons

| | Denoising proposed in this study with Bilinear interpolation | | | | | Present study |
|---|---|---|---|---|---|---|
| Image | 10% Noise | 25% Noise | 50% Noise | 75% Noise | 85% Noise | 85% Noise |
| 1 | 27.58 | 27.06 | 26.31 | 25.82 | 25.62 | 39.65 |
| 2 | 23.66 | 22.90 | 21.90 | 21.31 | 21.09 | 37.42 |
| 3 | 23.25 | 22.82 | 22.31 | 22.23 | 22.02 | 37.27 |
| 4 | 22.89 | 22.06 | 21.57 | 21.15 | 20.93 | 36.16 |
| 5 | 22.85 | 22.32 | 21.62 | 21.32 | 21.15 | 38.50 |
| 6 | 24.92 | 24.08 | 23.05 | 22.53 | 22.30 | 38.14 |
| 7 | 27.77 | 26.40 | 24.99 | 24.15 | 23.91 | 38.10 |
| 8 | 24.65 | 23.94 | 22.98 | 22.43 | 22.32 | 37.41 |
| 9 | 25.69 | 24.54 | 23.18 | 22.16 | 21.81 | 38.68 |
| 10 | 24.88 | 24.25 | 23.31 | 22.70 | 22.46 | 38.87 |
| 11 | 25.89 | 24.79 | 23.42 | 22.82 | 22.63 | 38.15 |
| 12 | 22.57 | 22.12 | 21.87 | 21.42 | 21.14 | 36.09 |
| Ave | 24.72 | 23.94 | 23.04 | 22.50 | 22.28 | 37.87 |

tested images. The CPSNR was used as a measure to quantify the performance of the demosaicing methods. It is defined as

$$\text{CPSNR} = 10\log_{10}\left(\frac{255^2}{\text{CMSE}}\right)$$

Where:

$$\text{CMSE} = \left(\frac{1}{3HW}\right)\sum_{i-r,g,b}\sum_{y=1}^{H}\sum_{x=1}^{W}\left(I_o(x,y,i) - I_r(x,y,i)\right)^2$$

where, $I_0$ and $I_r$ represents the original and the reconstructed images of sizes H×W

Table 1 shows the CPSNR Comparison of our method on 10, 25, 50, 75 and 85% of impulse noise with bilinear interpolation.

## CONCLUSION

A non-linear filtering for denoising with adaptive weighted color interpolation for digital still cameras use a single sensor equipped with color filter array is presented. Both the denoising and demosaicing algorithms make use of color difference value. The interpolation direction and weight value according to the edge value are used for interpolating missing green samples. The interpolated green pixel values along with the existing red and blue pixel values are used to interpolate the missed red and blue pixels. The denoising algorithm proposed in this paper is removing the impulse noise by preserving edges on low complex manner. Simulation results show that the proposed algorithm is able to produce subjectively and objectively better denoising with demosaicing results as compared with existing algorithms in terms of color peak signal to ratio.

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