

RESTORATION AND DEMOSAICING FOR PIXEL MIXTURE IMAGES IN DSC VIDEO CLIPS

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ABSTRACT

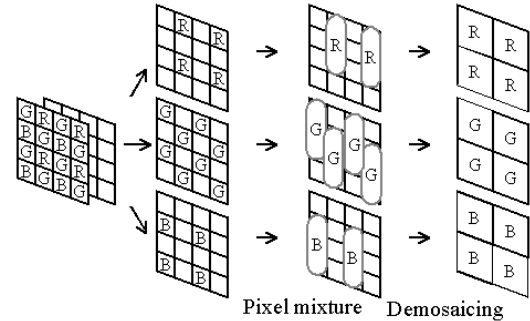
This paper proposes restoration methods for “pixel mixture”. Pixel mixture is a function for saving readout time for digital still cameras (DSCs), which mixes together two pixels on CCD. Pixel mixture reduces the number of pixels to be read out from CCD, and it enables video rate read out from DSCs of more than a million pixels. In this paper, an iterative method is presented in order to recover the image. Both restoration and demosaicing are performed at the same time. Our approach achieves the result of smaller mean square error than conventional interpolation methods.

1. INTRODUCTION

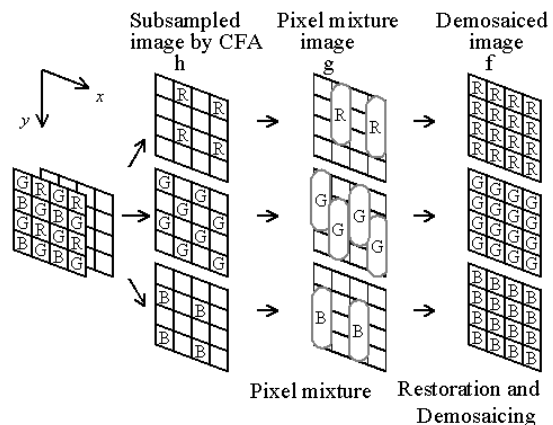
In recent years, DSCs are becoming higher resolution and higher functional. Most of DSCs now have video clip function. Some of high-resolution DSCs can record VGA size video clips at video rate with the help of pixel mixture on CCD [1]. Pixel mixture is mixing together two pixels on CCD. A pixel value is mixed with neighboring pixel values. Since the CCD is overlaid with a color filter array (CFA), the pixels under the same color filter should be mixed together. The amount of the information from CCD is compressed into half, and the readout time from CCD can be saved to half.

Generally, when neither line skipping nor pixel mixture is performed, the image outputted from CCD is demosaiced. Demosaicing is the process of reconstruction of a full-color image from interleaving of subsampled R,G,B images by CFA. We limit our discussion to Bayer CFA pattern as presented in Fig.1, which is used in the most of DSCs. In video clip mode, when pixel mixture is performed, the image outputted from CCD is demosaiced, and the size of the demosaiced image gets smaller (Fig.1(a)).

In this paper, we propose a restoration and demosaicing method for pixel mixture image. We restore the pixel-mixture image to the original full-resolution CCD image (Fig.1(b)). We also present post-processing using color correlation for removing color artifact. We will first introduce pixel mixture and demosaicing methods in Section 2, 3, respectively. Then we propose an iterative method of restoration and demosaicing for pixel mixture images in section 4. Section 5 presents the experimental results, and Section 6 concludes the paper.



(a) Conventional process in pixel mixture



(b) Proposed process in pixel mixture

Fig. 1. Pixel mixture and demosaicing process

2. PIXEL MIXTURE

Vertical pixel mixture, which means mixing two neighboring pixels of the same color in the same column, is performed on vertical CCD [2]. A pixel is mixed with the pixel two lines away for R,G,B images(Fig.2). On the other hand, horizontal pixel mixture, which means mixing two neighboring pixels of the same color in the same line, is performed on horizontal CCD [3]. In both cases, the readout time from CCD can be saved to half. In the rest of this paper, we discuss restoration and demosaicing from the vertical pixel mixture. The principle of the method is the same for the horizontal pixel mixture.

Simple line skipping or pixel mixture is performed on

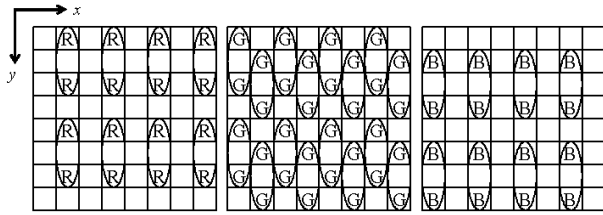


Fig. 2. Vertical pixel mixture pattern

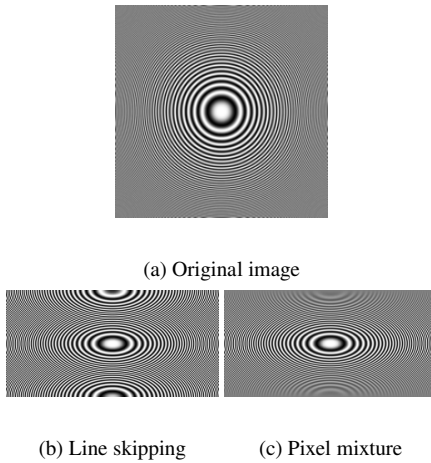


Fig. 3. Pixel mixture and line skipping images

CCDs for saving readout time. Line skipping causes aliasing artifacts and degradation such as jaggy. Since pixel mixture corresponds to averaging, pixel mixture image has smaller aliasing than simple line skipping image. In Fig.3, line skipping and pixel mixture images are shown in confirmation of pixel mixture effect. The original image (a) is a circular zone plate (CZP) computed by the Eq. (1). The image size is $n \times n$.

$$I(x, y) = 128 \cos\left(\frac{\pi}{n}x^2 + \frac{\pi}{n}y^2\right) + 128 \quad (1)$$

In the line skipped image (b), skipping a line every two lines of (a), the moiré is visible in the top and bottom. In the pixel mixture image (c), averaging two lines of (a), the moiré becomes much less. It is an advantage of pixel mixture that it reduces aliasing caused by simple line skipping.

3. DEMOSAICING

Concerning the demosaicing algorithm, many approaches have been proposed for the purposes of reducing color artifact and keeping sharpness. In [4]–[6], based on linear interpolation, directional correlation is used for keeping edges. And each color image is demosaiced using other color image's information, based on color correlation property, which means the strong correlation exists locally between the signals of three colors. Adaptive Color Plan Interpolation method (ACPI method) is based on linear interpolation and keeps edges by adding high-pass filtered images of other color [4].

On the other hand, demosaicing methods not based on

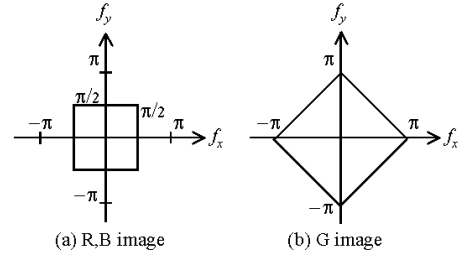


Fig. 4. Frequency bands of Bayer color filter array pattern

linear interpolation are also proposed. In [7], higher frequency of R or B was replaced by that of G, because the G image has more pixels than those of the R or B color image. In Fig.4, frequency bands of each color filter array pattern are shown. The frequency band of G filter array is wider than R, B. In [8], Landweber iterative method, one of the super-resolution methods, is also applied to demosaicing for the purpose of restoration of the lost high-frequency information.

4. RESTORATION AND DEMOSAICING FROM PIXEL MIXTURE

4.1. Restoration from Pixel Mixture by Interpolation

The R image of the vertical pixel mixture image g_R is given by Eq.(2), where h_R is the subsampled R image by CFA. If the restoration from the pixel mixture is accomplished, conventional demosaicing methods can be applied to the demosaicing of the restored image, and the demosaiced image is the same size in the case of normal readout.

0th-order interpolation (Eq.(3)) and linear interpolation (Eq.(4)) can be applied to the restoration from the pixel mixture, where \hat{h}_R is the restored R image. G and B images are restored by the similar equations. However the lost high-frequency information is not restored by these interpolation methods.

$$g_R(x, y) = h_R(2x+1, 4y) + h_R(2x+1, 4y+2) \quad (2)$$

$$\hat{h}_R(2x+1, 4y) = \hat{h}_R(2x+1, 4y+2) = \frac{1}{2}g_R(x, y) \quad (3)$$

$$\begin{cases} \hat{h}_R(2x+1, 4y) = \frac{1}{8}g_R(x, y-1) + \frac{3}{8}g_R(x, y) \\ \hat{h}_R(2x+1, 4y+2) = \frac{3}{8}g_R(x, y) + \frac{1}{8}g_R(x, y+1) \end{cases} \quad (4)$$

4.2. Restoration and Demosaicing by an Iterative Method

We apply Landweber iterative method [9] in order to restore the lost high-frequency information. Landweber iterative method is represented by

$$f_n = f_{n-1} + kA^*(g - Af_{n-1}) \quad (5)$$

where A is the degradation operator and A^* is the conjugate operator of A . g is the degraded image for input and f is the restored image for output. k is a constant.

We consider A as pixel mixture, subsampling by CFA and an optical low pass filter attached to CCD. Then g and f are regarded as a pixel mixture image and a estimated

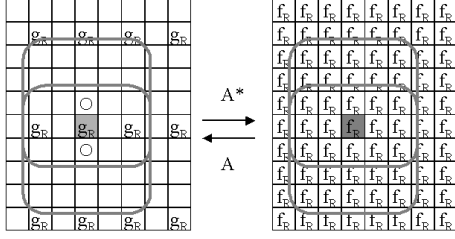


Fig. 5. Iterative restoration and demosaicing method for pixel mixture images

R_{11}	G_{21}	R_{31}	G_{41}	R_{51}
G_{12}	B_{22}	G_{32}	B_{42}	G_{52}
R_{13}	G_{23}	R_{33}	G_{43}	R_{53}
G_{14}	B_{24}	G_{34}	B_{44}	G_{54}
R_{15}	G_{25}	R_{35}	G_{45}	R_{55}

Fig. 6. Coordinates of post-processing

full-resolution CCD image, respectively. In our work, both restoration and demosaicing are performed at the same time. The Eq.(5) is computed independently in each R,G,B image.

In our experiments, the pixel mixture image g is produced in a computer. We used 5tap gaussian filter as the optical low pass filter and performed the subsampling by CFA and the vertical pixel mixture. The linear interpolation image of the pixel mixture image is used for the initial image f_0 of the iteration. The procedure of the iterative method is below (Fig.5).

1. Perform the gaussian filter to the initial image, sub-sample the position of CFA, and perform the vertical pixel mixture (Af_0).
2. Compute the difference image between the image given by 1 and the pixel mixture image ($g - Af_0$).
3. Divide the difference value into the positions before mixture (the positions of o in Fig.5) equally, and perform the gaussian filter ($A^*(g - Af_0)$).
4. Compute the difference image between the image given by 3 and the initial image ($f_0 + A^*(g - Af_0) = f_1$).

This procedure is repeated. The error compared to the pixel mixture image ($err = ||g - Af_{n-1}||$) is calculated in each iteration, and the iteration is finished when the decrease of the err stops. We can also finish the iteration before the decrease of the err stops for the purpose of saving computation time.

4.3. Post-Processing Using Color Correlation

In the previous subsection, the iterative method is performed independently in each R,G,B image, and color correlation is not taken into consideration. The optical LPF has effects of the reduction of aliasing and color artifact. Since frequency band of G filter array is wider than R, B (Fig.4), color artifact is produced again by restoration of high-frequency information. Then we present a post-processing method for

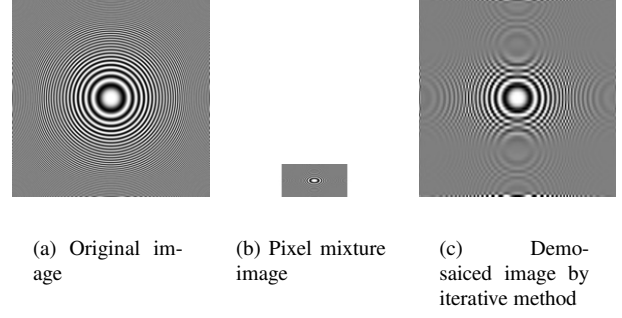


Fig. 7. R images of experimental results (CZP)

removing of color artifact. This method is applied to the demosaiced image given by the iterative method in the previous subsection.

In R images, the vertical and horizontal classifiers δ, γ are computed by Eq.(6). According to the classifiers, Eq.(7) is performed. Fig.6 shows coordinates for these equations. This process takes color correlation into consideration by adding band-pass filtered G images. The directional classifiers are introduced and improved from the ACPI method in order to keep edges. In B images, the similar process is performed. In G images, the post-processing is not performed.

$$\begin{aligned} \gamma &= |-R_{13} + 2R_{33} - R_{53}| + |-G_{13} + 2G_{33} - G_{53}| \\ \delta &= |-R_{31} + 2R_{33} - R_{35}| + |-G_{31} + 2G_{33} - G_{35}| \end{aligned} \quad (6)$$

$$R'_{33} = \begin{cases} (R_{13} + 2R_{23} + 4R_{33} + 2R_{43} + R_{53})/10 \\ \quad + (-G_{13} + 2G_{33} - G_{53})/4 & (\gamma < \delta) \\ (R_{31} + 2R_{32} + 4R_{33} + 2R_{34} + R_{35})/10 \\ \quad + (-G_{31} + 2G_{33} - G_{35})/4 & (\gamma > \delta) \\ (R_{13} + 2R_{23} + 4R_{33} + 2R_{43} + R_{53})/20 \\ \quad + (R_{31} + 2R_{32} + 4R_{33} + 2R_{34} + R_{35})/20 \\ \quad + (-G_{13} - G_{31} + 4G_{33} - G_{53} - G_{35})/8 & (\gamma = \delta) \end{cases} \quad (7)$$

5. EXPERIMENTAL RESULTS

We tested the proposed method on a CZP image. After subsampling and pixel mixture, the restoration and demosaicing were performed. Fig.7(a),(b),(c) show R images of the original image, the vertical pixel mixture image and the demosaiced image by the iterative method, respectively. The frequencies at the corner of the original image (a) are set equal to the Nyquist frequency.

Fig.8 shows a part of the color images of Fig.7. As a reference, the demosaiced images by the interpolation and ACPI method are shown together. Fig.8(b) is the image restored by 0th-order interpolation and demosaiced by ACPI method. (c) is the image restored by linear interpolation and demosaiced by ACPI method. (d) is the demosaiced image by the iterative method, and (e) is the post-processed image of (d) by the color correlation method. Jaggy is visible in Fig.8(b), and sharpness is less in (c). The demosaiced image by iterative method (d) has more sharpness, and the jaggy

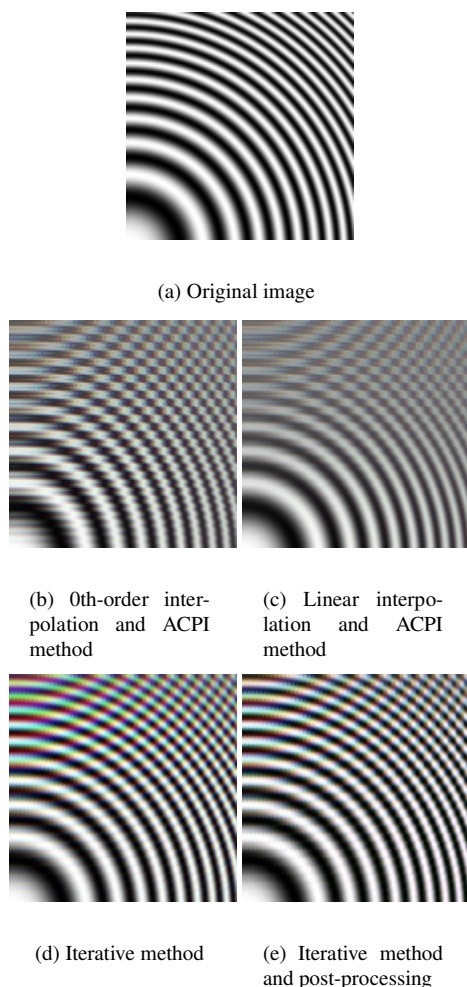


Fig. 8. Demosaiced images (CZP)

is not very visible. The post-processed image (e) has improved color artifact. Table 1 shows the mean square errors compared to the original image. In each color image, the result of iterative method has smaller errors than interpolation and ACPI method. The result of post-processing has still smaller errors.

We tested also the proposed methods on the ITE standard movie for HDTV (Walk through the Square). We used continuous 100 frames out of the sequence. Pixel mixture and demosaicing are performed on every frame. Fig.9(a),(b) show R images of the vertical pixel mixture image and the demosaiced image by the iterative method, respectively. The mean square errors compared to the original images are computed in each frame. The average mean square errors in 100 frames are shown in Table 1(b). Similar to Table 1(a), the result of iterative method has small errors.

6. CONCLUSIONS

We have proposed the restoration and demosaicing method for pixel mixture images. We examined the restoration method

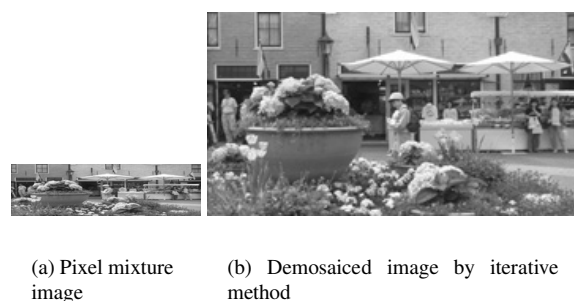


Fig. 9. R images of experimental results (HDTV)

Table 1.
(a) Mean square errors (CZP)

Restoration and demosaicing methods	R	G	B
0th-order interpolation and ACPI method	6242	5974	6242
Linear interpolation and ACPI method	6541	6339	6541
Iterative method (number of iteration)	5981 (3)	4712 (10)	5981 (3)
Iterative method and color correlation	4888	-	4888

(b) Mean square errors (averaged 100 frames)(HDTV)

Restoration and demosaicing methods	R	G	B
0th-order interpolation and ACPI method	77.2	76.9	83.8
Linear interpolation and ACPI method	82.0	75.7	90.8
Iterative method (number of iteration)	48.5 (3)	26.5 (5)	53.8 (3)
Iterative method and color correlation	42.4	-	45.7

based on Landweber iterative algorithm. Our approach achieves the result of smaller mean square errors than the conventional interpolation methods. Smaller mean square errors are obtained by post-processing using color correlation method.

7. REFERENCES

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