A Pseudo Multiple Capture CMOS Image Sensor with RWB Color Filter Array

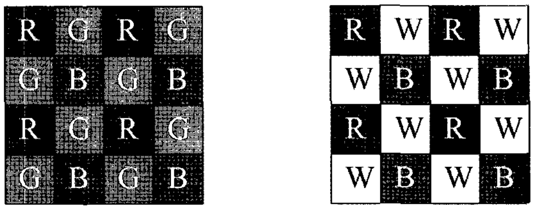
Juseop Park, Kunil Choe, Jimin Cheon, and Gunhee Han

***Abstract*—A color filter array (CFA) helps a single electrical image sensor to recognize color images. The Red-Green-Blue (RGB) Bayer CFA is commonly used, but the amount of the light which arrives at the photodiode is attenuated with this CFA. Red-White-Blue (RWB) CFA increases the amount of the light which arrives at photodiode by using White (W) pixels instead of Green (G) pixels. However, white pixels are saturated earlier than red and blue pixels. The pseudo multiple capture scheme and the corresponding RWB CFA were proposed to overcome the early saturation problem of W pixels. The prototype CMOS image sensor (CIS) was fabricated with 0.35-μm CMOS process. The proposed CIS solves the early saturation problem of W pixels and increases the dynamic range.**

***Index Terms*—CMOS image sensor (CIS), Color filter array (CFA), Red-White-Blue (RWB), Saturation, Wide dynamic range, Pseudo multiple capture scheme**

I. INTRODUCTION

A color filter array (CFA) plays an important role in perception of color scenes for a single electrical image sensor [1]. The Red-Green-Blue (RGB) Bayer CFA [2] is the most commonly used CFA described in Fig. 1 (a). The amount of the light which arrives at the photodiode is attenuated by the CFA, because the color filters pass only their specific spectral components. The Red-White-Blue (RWB) CFA [3] uses white (W) pixels instead of green (G) pixels as shown in Fig. 1 (b). RWB CFA increases the light intensity at photodiode (PD) with W pixels which have no color filters. However, W pixels are saturated earlier than red (R) and blue (B) pixels owing to increased light intensity.



(a) RGB CFA [2] (b) RWB CFA [3]

Fig. 1. Bayer color filter arrays.

This paper proposes a modified RWB CFA and the pseudo multiple capture scheme to overcome the early saturation of the W pixel. Section 2 describes the proposed CFA and Section 3 proposes the pseudo multiple capture scheme. The experimental results are presented in Section 4. The conclusion is provided in Section 5.

II. MODIFIED RWB COLOR FILTER ARRAY

The normalized spectral response of the primary RGB color filters and W filters are arranged in Fig. 2, and the area under the response curve means the signal of each component. The signal of W pixel is three times larger than that of conventional G pixels. As a result, the RWB CFA provides higher sensitivity and signal to noise ratio (SNR) with increased image information conveyed by light than RGB CFA. However, the photodiode (PD) potential of W pixel reaches to saturation earlier than the others PD in R or B during the integration time as shown in Fig. 3. The saturation of the W pixel results in the

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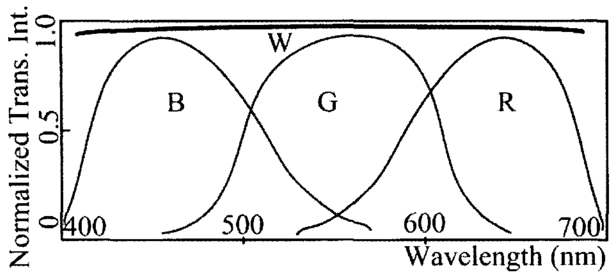


Fig. 2. Spectral response of color filters.

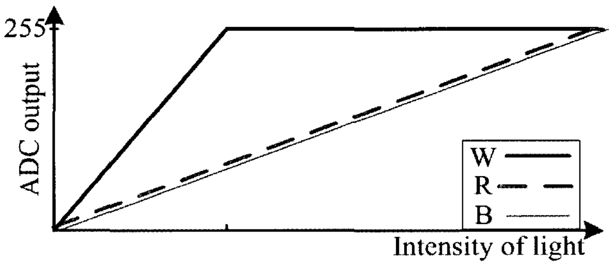


Fig. 3. Early saturation problem in W pixels.

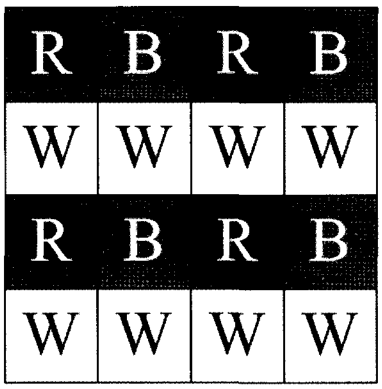


Fig. 4. Proposed CFA.

information loss, so restored image with distorted W components can be derived from image sensor with RWB CFA. This is the reason why special schemes like regulating the integration time for W pixel to prevent early saturation are essential.

Special schemes for solution of W pixel are easily applied by separating W pixels and color pixels of RWB Bayer pattern. Considering interpolation, regularly arranged CFA patterns which have uniform pixel distances to adjacent pixels are recommended. Fig. 4 shows the proposed RWB CFA individually, and this arrangement allows the special schemes more efficiently. The special scheme applied in the proposed RWB CFA is pseudo multiple capture scheme and details of the proposed scheme is followed in the next section.

III. Pseudo Multiple Capture Scheme

The pseudo multiple capture scheme is proposed to overcome the early saturation problem in W pixels and improve the dynamic range. This scheme adopts the dual sampling technique [4] only for W pixels. Fig. 5 shows the timing of the pseudo multiple capture scheme. T is the integration time that does not cause the saturation in R or B pixels. While R and B pixels integrate the photocurrent during integration time T, the integration time of W pixels is divided into mT and $(1-m)T$, where $0 < m < 1/3$. The time index m can be controlled under certain fixed illumination environment.

The output after integration time of mT and integration time of $(1-m)T$ are denoted as W_1 and W_2, respectively. As the gain is proportional to the integration time, the response of W_1 and W_2 can be depicted as shown in Fig. 6, where the output value is normalized by the gain of R and B pixels. The W_1 of each pixel is stored in the external frame memory and the final W pixel value is computed as follows when W_2 is available.

$$\begin{cases} W = \frac{1}{2}\left(\frac{W_1}{m} + \frac{W_2}{1-m}\right) & (W_2 < W_{MAX}) \\ W = \frac{W_1}{m} & (W_2 = W_{MAX}) \end{cases} \quad (1)$$

In Equation (1), the computed W pixel value is denoted W. If W_2 is saturated, W_T is determined only with W_1. If W_2 is not saturated, W_T is computed by multiplying the gain factors to W_1 and W_2, respectively. This pseudo multiple capture allows increased dynamic range as shown in Fig. 6 The required readout speed and frame memory requirement for multiple sampling are reduced by half than the conventional dual capture scheme because only the white pixels are multiple captured.

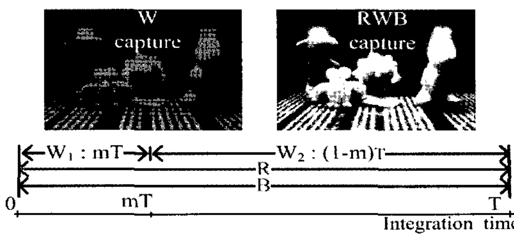


Fig. 5. Timing of pseudo multiple capture scheme.

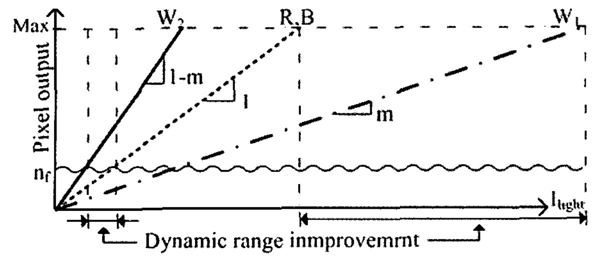


Fig. 6. Concept of pseudo multiple capture scheme.

IV. EXPERIMENTAL RESULTS

The CMOS image sensor (CIS) with the proposed RWB CFA is fabricated with 0.35-μm CMOS process. The photograph of the fabricated chip is shown in Fig. 7. This chip has 320 column wise readout blocks composed of analog to digital converter (ADC) and correlated double sampling (CDS) circuits. In the center of the chip, there are 320×240 pixel arrays. The CFA format on the pixel is the same as shown in Fig. 4 and pixels have 4-TR structure with the pinned PD whose size is 5.6 μm x 5.6 μm . Since the image signal processing (ISP) circuit or the frame buffer memory for the multiple capture are not fabricated within the prototype CIS, the W values from the first capture are stored in the external memory until the second frame is captured and image signal processing is done with the external processor.

The measured spectral responses of the RWB CFA are shown in Fig. 8 (a). Because the output of a pixel is not only the response of CFA but also that of photodiodes, the W pixel response is not flat over all spectral regions but three times larger than R and B pixel response. Fig. 8 (b) describes the sensor output in accordance with the change of the light intensity and the W pixel value is three times larger than the R and B pixel values under the same light intensity, but it is saturated earlier than the R and B pixel.

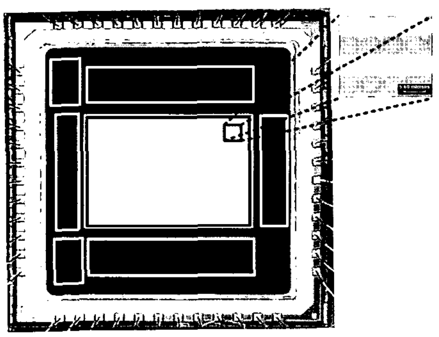
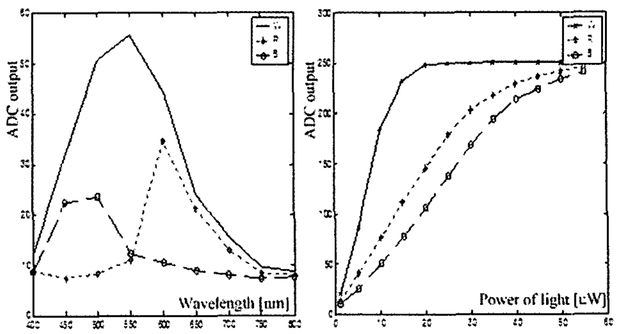


Fig. 7. Photograph of fabricated chip.



(a) spectral response (b) light intensity response

Fig. 8. Measured results.

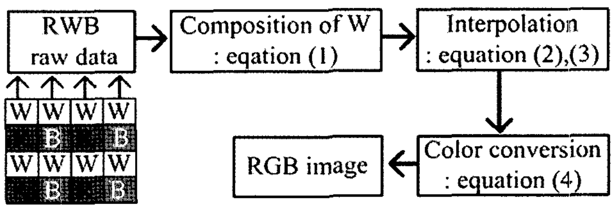


Fig. 9. Image signal processing.

Fig. 9 shows the flow of the post processing. The first step of the post processing is the composition of W from multiple captured values, W_1 and W_2, as described in Equation (1). The second step is interpolation. The sparse sampling of RWB information from CIS gets total color information of all the pixel location by this interpolation step. Since the interpolation algorithm is not the issue of this paper, a simple first order interpolation is carried out by averaging neighbor pixel values. Fig. 10 shows raw image data from image sensor with proposed CFA pixel indices are used to distinguish the position. For example, missing values in the location of R_2 and W_6 are determined as follows in Equation (2) and (3), respectively.

$$\begin{cases} W_7 = \dfrac{W_2 + W_4 + W_{11}}{3} \\ B_7 = \dfrac{B_6 + B_8}{2} \end{cases} \tag{2}$$

$$\begin{cases} R_{10} = \dfrac{R_5 + R_7 + R_{14}}{3} \\ B_{10} = \dfrac{B_6 + B_{13} + B_{15}}{3} \end{cases} \tag{3}$$

The third step is color conversion. The RWB information is converted to RGB information by color

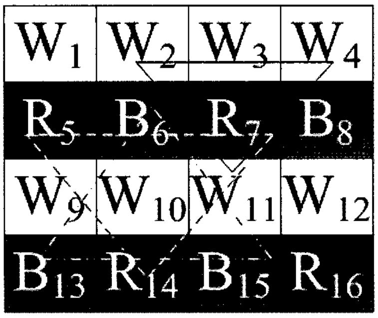
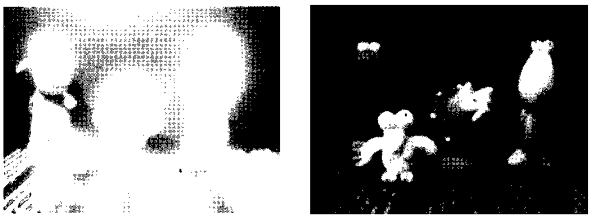


Fig. 10. Interpolation method.



(a) Image without proposed scheme (b) Image with proposed scheme

Fig. 11. Reconstructed color image.

Table 1. Characteristics of the fabricated CIS.

Process	CMOS 0.35- μm process
PD type	Pinned PD
Array format	Active : 320 × 240
Chip size	3.6 mm × 3.4 mm
Effective imaging area	1.85 mm × 1.4 mm
Pixel size	5.6 μm × 5.6 μm
Fill factor	37 %
Video output	8 bits
Power supply	3.3 V
Power consumption	45 mW

conversion process. Since the spectral response of the W pixel is not flat over the visible light spectral range as shown Fig. 8 (a), the color conversion matrix is experimentally obtained as follows in Equation (4).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0.33 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R \\ W \\ B \end{bmatrix} \qquad (4)$$

Fig. 11 shows the reconstructed images. Fig. 11 (a) is the reconstructed image without multiple capture scheme and Fig. 11 (b) is the reconstructed image with the pseudo multiple capture with $m = 1/3$ for simplicity of the functionality test. The earlier saturation problem in W pixel is overcome by the pseudo multiple capture scheme.

The specification of the fabricated CIS is summarized in Table. 1.

V. CONCLUSIONS

A modified RWB CFA structure and the pseudo multiple capture scheme to overcome the early saturation of the white pixel have been proposed. The prototype CIS with this CFA and readout scheme was fabricated.

The CIS with proposed CFA detects light signal more efficiently under low illumination environment due to high sensitivity of W pixels. The CIS proposed scheme improves dynamic range by extending allowable light signal range under high illumination environment. The proposed RWB CFA and pseudo multiple capture scheme relieves the frame memory requirement and readout speed by half, respectively.

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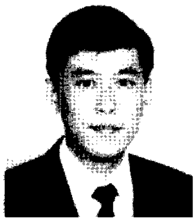

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