Advanced RGBW OLED Display System with Novel RGB-to-RGBW and Subpixel Rendering Algorithm

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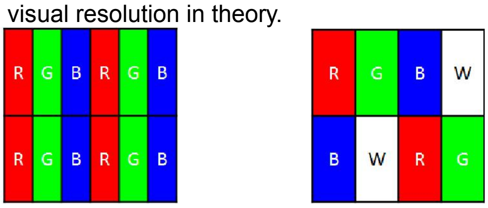
ABSTRACT

The new RGB-to-RGBW and subpixel rendering were proposed. The former is applied to enhance luminance and decrease color-distortion, the latter is designed to scale the virtual resolution. Experimental result shows that the proposed method increases the average intensity by 23% with a color-distortion level of 0.013, meanwhile it almost identical to real RGB resolution.

1. INTRODUTION

In OLED displays composed of WOLED backplane and color filter, it is useful to increase luminance at lower cost of power consumption, which can also extent OLED life time. Fortunately, RGBW displays can friendly improve the energy efficiency, since there is no color dye on the additional white pixel. Fig. 1 shows a typical sub-pixel structure of a RGB and RGBW display with the same visual resolution in theory.



(a) RGB layout (b) RGBW checkerboard layout

Fig. 1 The subpixel structure of (a) RGB and (b) RGBW display system

By adding a white subpixel as shown in Fig. 1(b), the total transmittance of the RGBW display is about 1.5 times that of the RGB one with same energy consumption; that also implies it can reduce the power consumption while maintaining the same luminance level[1]. However, the challenge is the absence of a proper RGB-to-RGBW mapping algorithm, which is an essential factor for maintaining the original saturation and hue. Hence the trade-off between luminance and color distortion is evaluated in a perception experiment.

The number of subpixel is reduced by 1/3 compared with the real RGB layout, so the number of column driver is reduced by 1/3. By this way, the panel yield rate should be improved dramatically and also provide low cost but good image quality display. Although the actual subpixel room has been cost down, the apparent resolution can be approached to the real RGB resolution by using special subpixel rendering algorithm[2].

2. OLED RGBW IMAGE PROCESSING ALGORITHMS

The proposed method has two important goals; the first one is to reduce color distortion and increase intensity as much as possible after RGB-to-RGBW conversion, the other is to raise the virtual visible resolution[2]. The flow chart of concrete algorithm, as shown in Fig. 2, is an answer how to deal with this challenging task.

The proposed method is mainly composed of two steps: RGB to RGBW conversion and subpixel rendering. In the first step, RGB signals are converted into RGBW signals by applying uniform gain based on scene-adaptively considering the data clipping of the pixels, which can obtain the stable W_o component. In the final phase, the smooth edge information and saturated details, especially for single-pixel line, can be well represented.

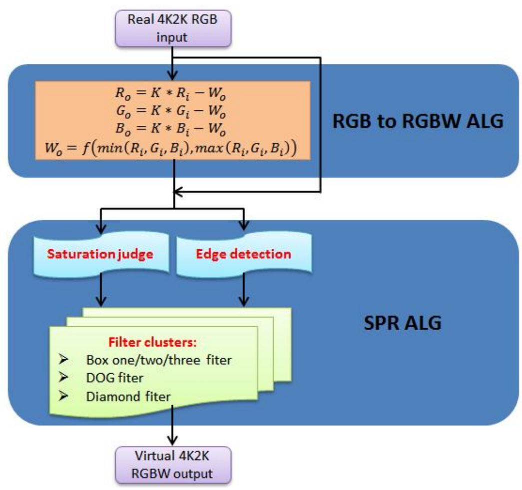


Fig. 2 The flow chart of proposed method

2.1 RGB to RGBW conversion

The way RGB converting to RGBW will determine the image color and intensity[1, 3]. The well-known about replacement method and the enhancement method are forced to do this[4]. For mitigating the color distortion, we plan to employ the enhancement method to eliminate the annoyance.

$$\begin{cases} R_o = K * R_i - W_o \\ G_o = K * G_i - W_o \\ B_o = K * B_i - W_o \\ K = 1 + W_0 / max(R_i, G_i, B_i) \\ W_o = f\big(min(R_i, G_i, B_i), max(R_i, G_i, B_i)\big) \end{cases} \quad (1)$$

$$W_o = k1 * min^5 + k2 * min^4 + k3 * min^3 + k4 * min^2 + k5 * min + k6 \quad (2)$$

Equation 1 represents the enhancement method of RGB-to-RGBW mapping algorithm. According to component W_o obtained by method described in reference[1], W_o value is not fully utilizing the feasible emission efficiency. On the basis of research results, a new extracting method as shown in equation 2 is proposed to obtain W_o value to get better efficiency. It is straightforward to see that the proposed method is higher intensity than existed method according to Fig. 3, where the red region represents the W_o luminance range from proposed method, and the green region represents the W_o luminance range from reference method. As shown in Fig. 4, the W_o by proposed transform function has higher magnitude than the ones from previous method.

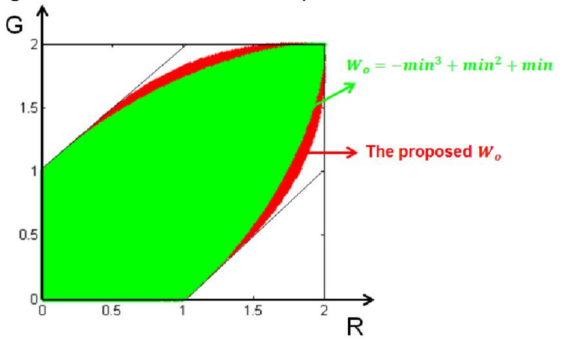


Fig. 3 the luminance range of W_o

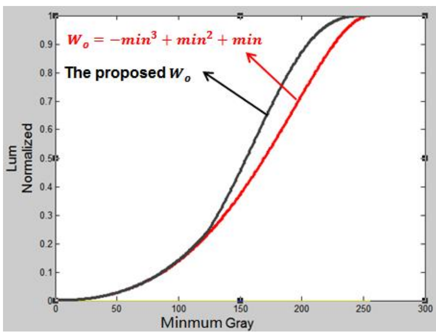


Fig. 4 the luminance value of W_o

2.2 Sub-Pixel rendering (SPR)

In this section, we need to shrink a high resolution image (Ex. 3840×2160×RGB) into fit the real 31'' RGBW OLED display (3840×2160×(RG) or (BW)). The goal is trying to scale the virtual resolution on low resolution panel with similar visual quality. While improper method is applied, the drawback including losing high-frequency detail and sawtooth on the edge will downgrade the image quality[5]. Various algorithms are proposed to overcome or ease the side effect. In this paper, a new sub-pixel rendering flow are developed, which comprises the following three steps: (1) detecting the edge pixels on the original RGB image by sobel operator, (2) judging the saturation vector of original RGB, (3) treating different cases with specific filter.

(1) Edge detection

In order to reconstruct high-frequency information to keep the image sharp, a method to detect edge of original image is essential. A simple 3x3 sobel operator is convoluted with intensity component of image to generate edge map while the gradient value greater than given threshold will be recorded as edge or remarked as plan area.

(2) Saturated pixel decision

The saturation value can be computed as equation 3. In some embodiments, for each pixel, the saturation value is set to 1 if the following value "v_sat" is above some threshold, whereas is 0.

$$v\_sat = \frac{min(R_i, G_i, B_i)}{\max(1, R_i, G_i, B_i)} \quad (3)$$

(3) Special filters design

In this implementation, the display of RGBW type is composed of red, green, blue and white subpixels with equal emission area size. Each set of subpixels, which are named as "RG pair" and "BW pair", consist of two adjacent subpixels alternate in each row and each column as above mentioned in Fig. 1(b). That can provide high resolution with wide luminance range. Here just illustrates the SPR operation of the red subpixels as below, and the other subpixels are processed in a similar manner.

The specific pattern can be detected by applying different 3x3 matrix on original images, the detail procedure can be divided into following steps: Firstly, determining whether there exists edge pixels in a 3×3 domain around the central pixel, if the answer is "NO", we can adopt the general subpixel sampling method to calculate the red subpixel output value. On the contrary, we need continue to judge whether there exists saturated pixels in a 3×3 domain around the central pixel. If the answer is "NO", the Ro value of each red subpixel is determined as a weighted sum of the R coordinates of all the pixels which overlap with the sampling area, and the adopted kernel filters are diamond filter and DOG filter, which are illustrated in Fig. 5 and equation 4. Otherwise some special box filters are designed to deal with the following three different severe cases respectively.

$$\boldsymbol{R_o} = -\mathbf{1/16} * (\boldsymbol{R_{i-1,j-1}} + \boldsymbol{R_{i+1,j-1}} + \boldsymbol{R_{i-1,j+1}} + \boldsymbol{R_{i+1,j+1}}) + \frac{\mathbf{1}}{\mathbf{8}} * \left(\boldsymbol{R_{i,j-1}} + \boldsymbol{R_{i-1,j}} + \boldsymbol{R_{i+1,j}} + \boldsymbol{R_{i,j+1}}\right) + \mathbf{3/4} * \boldsymbol{R_{i,j}} \quad (4)$$

P(i-1, j-1)	P(i, j-1)	P(i+1, j-1)
P(i-1, j)	P(i, j) Central pixel	P(i+1, j)
P(i-1, j+1)	P(i, j+1)	P(i+1, j+1)

(a) The location of central pixel

0	1/8	0
1/8	1/2	1/8
0	1/8	0

(b) Diamond filter

-1/16	0	-1/16
0	1/4	0
-1/16	0	-1/16

(c) DOG filter

Fig. 5 Different kernel filters

Case I: If saturated R subpixel in a 3×3 region is consistent with any case shown in Fig. 6, then it is performed using the BOX1 filter by equation 5.

$$R_o = 1/2 * (R_{i,j} + R_{i+1,j}) \quad (5)$$

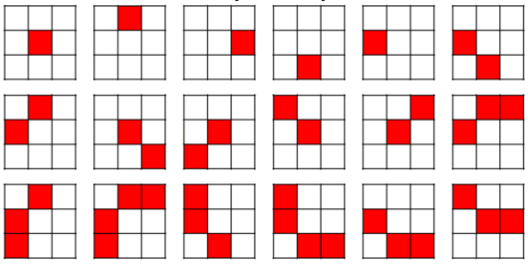


Fig. 6 the patterns in case one

Case II: While saturated R subpixel in a 3×3 region is consistent with any case shown in Fig. 7, then it is performed using the BOX2 filter by equation 6.

$$R_o = R_{i+1,j} \quad (6)$$

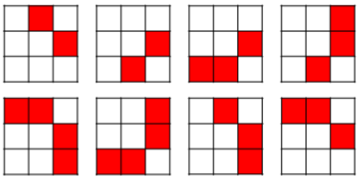


Fig. 7 the patterns in case two

Case III: If saturated R subpixel in a 3×3 region is consistent with any case shown in Fig. 8, then it is performed using the BOX3 filter by equation 7.

$$R_o = R_{i,j} \quad (7)$$

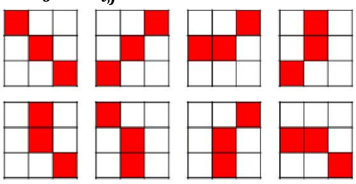


Fig. 8 the patterns in case three

3. EXPERIMENTAL RESULTS

The color distortion and intensity increment are evaluated using various typical images. Table 1 shows experimental results based on different methods. The proposed method has 8.95% in the intensity increment than the conventional method on average. Moreover, it also maintains a lower color distortion about 0.013 that indicates the proposed algorithm can guarantee uniform image quality over different scenes.

Table 1 Comparison results of normal method and the proposed algorithm

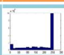
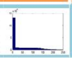
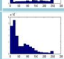
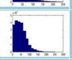
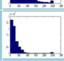
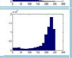
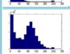
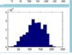
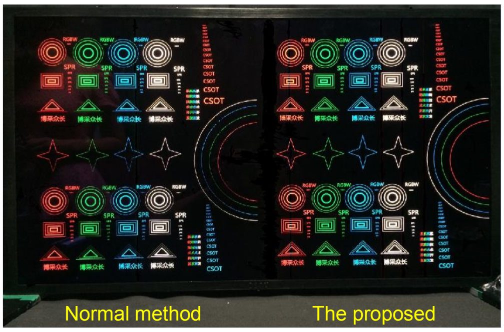
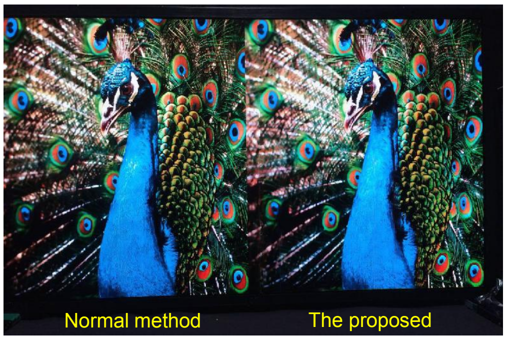
Name	Image	Saturation (0~100)	Intensity (0~100)	Histogram of S	Histogram of I	Luminance of ALG (0~100)			Color distortion	
						Origin	Normal	CSOT	Normal	CSOT
Spoon		71 (H)	13 (L)			6	5.5	5.8	0.018	0.014
Lotus		25 (L)	20 (L)			4.6	5.5	5.9	0.025	0.022
Snow		14 (L)	73 (H)			56.5	77.4	86.3	0.008	0.007
Uluru		35 (M)	49 (M)			25.5	27.8	31	0.012	0.009

Fig. 9 shows two real pictures of the developed 31-inch RGBW OLED prototype by CSOT. It illustrates that our algorithm about SPR can make continuous and clear image, especially for high-frequency information, without clipping or blurring artifacts. According to the nature scenery, our prototype platform can make very bright and vivid colors.



(a)



(b)

Fig. 9 Comparison results with two methods

4. CONCLUSION

RGBW OLED displays have the benefit of better transmittance and longer life time than conventional RGB OLED displays. However some difficulties need to be overcome by advanced algorithms. This paper proposes a novel RGB-to-RGBW conversion method that extends the luminance range and enhances intensity. Furthermore, a sub-pixel rending technology is also implemented to scale virtual resolution on low-resolution platform with good image quality.

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