©2016 Society for Imaging Science and Technology

High resolution LED display using a new rendering method with color sub-pixel architecture

Dae-Sik Kim, Sang-Kyun Im, Tetsuya Shigeta and Ho-Sup Lee
Samsung Electronics, DM&C R/D Center, 416, Maetan-3-Dong, Yeongtong-gu, Gyeonggi-do, Suwon-si 443-742, Republic of Korea
E-mail : daesikkim@samsung.com

Abstract

We have developed a novel LED display with RGGB color architecture with 4sub-pixels rendering. Sub-pixel rendering is known as a method of the perceptual enhancement of conventional display resolution higher than normal pixel rendering. In this paper, LED light control filter algorithm is proposed in order to reduce the color fringe artifact by sub-pixel rendering. A new LED display which has RGGB 4 sub-pixel structure with filtered sub-pixel rendering is evaluated by comparing the simulated MTF and visual test of the displayed wedge pattern. The results show that it has 2 times higher perceptual resolution without color fringe artifact and it is possible to be about 30% cost cutting.

1. INTRODUCTION

LED Display had been able to display full-color image using RGB 3 primary color LED after realizing Blue Led production. Currently, large area LED display panels are widely used as indoor and outdoor display for showing advertisement and some information to many people in public area such as streets, shopping malls, parks, exhibition halls and sports stadiums.

One of the reasons why LED's are using for large area display is LED's have a characteristic of very high brightness. However, the material cost in panel device is much higher because of using many LED chip as discrete part and it has limitation to improve resolution without expanding panel size due to the restriction of LED chip size with packaging.

Otherwise, some sub-pixel rendering methods had been proposed to improve resolution compare to conventional 3-prime-color-1-pixle structure. [1,2,3] The structure of these are normal 3 prime color sub-pixel, adding one of prime color to 3 prime color, adding different color to 3 prime color, adding white sub-pixel to 3 prime color, and so on. In any structure, sub-pixel rendering method causes annoying artifact. It's a sight of false color on high space frequency image like as high contrast edge, called color fringe artifact generally. Some methods are proposed for suppressing the color fringe artifact. For example, there are pixel selecting algorithms with down sampling, some signal processing filters before down sampling and so on.

In this paper, we propose a new method of suppressing color fringe artifact with improve resolution for sub-pixel rendering in the Bayer matrix sub-pixel arrangement and evaluate perceptual resolution how higher than conventional sub-pixel arrangement with normal pixel rendering by new MTF simulation and displaying experiment

2. PIXEL ARRANGEMENT AND RENDERING

The conventional LED Displays has pixel structure including only RGB 3 prime color. In order to improve resolution, some sub-pixel structures and some sub-pixel rendering methods are proposed. A sub-pixel rendering is displaying independent data in each sub-pixel. Our method is RGGB structure, called Bayer's matrix, with sub-pixel rendering. [4] Figure.1 shows conventional and our sub-pixel structure and rendering way.

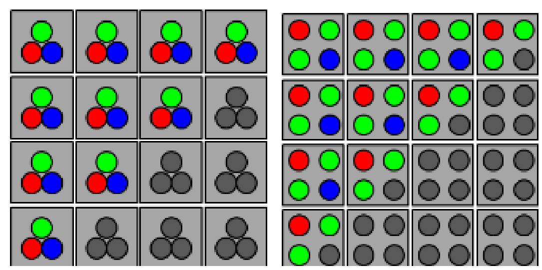

Fig.1. RGB sub-pixel structure with pixel rendering (left), RGGB sub-pixel structure with sub-pixel rendering (right)

3. COLOR FRINGE COMPENSATION

In the sub-pixel rendering method, annoying color error, called color fringe artifact, occurs in high contrast edge image because one pixel data is displayed on only one sub-pixel as prime color. We can recognize the color as original image color in low frequency image since we see the pixel with surrounding sub-pixels compensating color each other. But the color fringe can be seen in high frequency image because of lack or weakness of other sub-pixel color.

We have developed the light control filter algorithm adapted the characteristics of LED displays which are sharp spectrum of each color LED and low fill factor of sub-pixel area. It aims both improvement of resolution and reduction of color fringe artifact. It uses 4 types of 7x7 2-D matrix filter that has different matrix parameter. Each filter is selected by two conditions which are sub-pixel colors (G and R/B) and direction of edge (positive and negative) in image as below equations. A general 3x3 HPF is available to detect the direction of edge. If the data exceeds maximum value in this process, it is limited to maximum. Figure.2 shows PSF (Point Spread Function) of each matrix filters. These filters have characteristic of circular symmetry.

$$S_{out}(x,y) = H(x,y) * s_{in}(x,y)$$

$$H(x,y) = \begin{cases} H_{gp}(x,y) & Green, Positive\ edge \\ H_{gn}(x,y) & Green, Negative\ edge \\ H_{rbp}(x,y) & Red/Blue\ , Positive\ edge \\ H_{rbn}(x,y) & Red/Blue\ , Negative\ edge \end{cases}$$

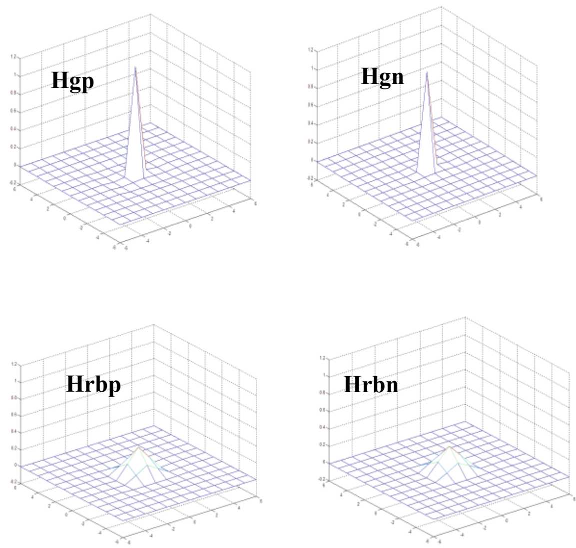

Fig.2. PSF of each matrix filter

Table.1. PSNR of chrominance signal

	Conventional DSR		Novel Light Control Filter			
	PSNR(U)	PSNR(V)	PSNR(U)	Δ	PSNR(V)	Δ
Image1	29.21dB	29.95dB	32.53dB	3.32dB	32.76dB	2.81dB
Image2	28.98dB	29.25dB	31.65dB	2.67dB	31.46dB	2.21dB
Image3	26.75dB	27.36dB	30.17dB	3.43dB	30.23dB	2.87dB
Image4	31.26dB	31.63dB	34.24dB	2.98dB	33.90dB	2.27dB
Image5	29.33dB	30.43dB	33.00dB	3.67dB	33.48dB	3.05dB

(a)

(b)

(c)

(d)

(e)

Fig.3. PSNR evaluation of the images provided by Kodak ;
(a) Image 1, (b) Image 2, (c) Image 3, (d) Image 4, (e) Image 5

The effect of this filter for reduction color distortion is evaluated by PSNR (Peak Signal to Noise Ratio). The PSNR of chrominance signal U and V are calculated for 5 images which being provided by Kodak. [5] Table.1 shows the result of calculated PSNR comparing conventional direct sub-pixel rendering (DSR) method and our light control filter algorithm. Our method has about 3dB higher PSNR than non-filtered DSR method.

Figure.4 shows the result of image simulation for image4. In the case of conventional method, there are color fringe artifacts in white pale image. However these artifacts are disappeared on our light control filter method.

4. COLOR FRINGE COMPENSATION

4.1 Evaluation of resolution by Calculation

It is evaluated by calculation how the method of RGGB structure with filtered sub-pixel rendering (RGGB-FSR) improve rather than RGB structure with normal pixel rendering (RGB-PR).

VESA defines measurement of resolution from contrast modulation using black and white lines. It is applied for normal pixel rendering, and it is not defined for sub-pixel rendering. After we calculated a resolution for our RGGB-FSR by VESA's definition, it was higher than actual perceptual resolution even though using threshold as 50% for text and graphics images.

Therefore, we propose a new evaluation way to compare the perceptual resolution between normal pixel rendering and sub-pixel rendering. It uses MTF (Modulation Transfer Function) comparison. MTF is amplitude response for sine wave.

In our evaluation, MTF is defined as function how an analog image in the natural world can be represented by display device with digitized pixel structure exactly, so it is calculated amplitude response for analog sine wave input.

$$s_\omega = \frac{A_{in}}{2}\{\sin(\omega t + \vartheta) + 1\}$$
$$MTF_\omega = \frac{|H(s_\omega)|pp}{A_{in}}$$
$$| \quad |pp : peak\ to\ peak\ in\ 1\ cycle$$

Because there are any types of amplitude levels (A_in) and phases (θ) in natural world, the average for these must be calculated. At first, the simple average MTF for phases that change from 0[deg] to 360[deg] is calculated for each amplitude level.

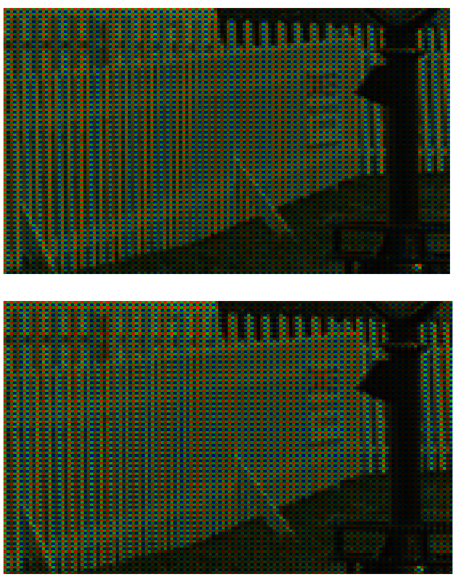

Fig.4. Simulated images for color fringe. Conventional direct sub-pixel rendering (upper). Novel filtered sub-pixel rendering (lower)

There are any phases of position for any things in natural world. The resolution of display has to be evaluated the ability of displaying these things with any phases. In the case of digital display device, it is not be able to display any phases for things even though its frequency in space is lower than 0.5cycle/pixel that is nyquist frequency. For example, the image that frequency is 0.5cycle/pixel is displayed as amplitude 0 level signal if its pixel sampling phase is shifted to 90 degree from the position where it can be displayed the image with exact amplitude level. In order to evaluate MTF exactly to consider effects for phase different of input images, the MTF must be calculated average for phases of input signal. The accumulation of amplitude ratio between input signal and display output with shifting phase of input analog sine wave from 1 degree to 360 degree is calculated and then the average for these is calculated to get phase averaged MTF. The amplitude ratio is calculated peak-to-peak level of output divided by peak-to-peak level of input for 1 cycle because the phase for pixel sampling point changes in 2nd phase.

$$MTF_\omega(A_n) = \frac{1}{360}\sum_{\theta=1}^{360}\frac{|H(s_\omega)|pp}{A_{in}}$$

And also there is any amplitude in input signal. The average calculation is needed for amplitude level of signal because the result of displaying is different for input level. It means that the calculation of phase averaged MTF is done for each amplitude level of input sine wave. But, because the amplitude level is not uniform distribution, the weighted value gotten from amplitude distribution for standard video image is used for weighted average calculation.

$$MTF_\omega = \sum_{n=0}^{N-1} k_n \cdot MTF_\omega(A_n)$$
$$k_0 + k_1 + k_2 + \cdots + k_{N-1} = 1$$

Figure5 is graph chart that shows calculation result of MTF for RGB structure with normal pixel rendering and RGGB structure with sub-pixel rendering. In order to compare how RGGB structure is higher resolution than RGB structure, it is necessary to define the reference MTF level to compare space frequency. We defined that the reference is averaged MTF level at 0.5[cycle/pixel] which is maximum space frequency can be displayed on RGB structure with normal pixel rendering. It is averaged peak-to-peak level of signal sampled by half cycle (π) pitch for analog sine wave. The equation is below. The reference is set 0.6366 by calculation result.

$$\frac{1}{\pi}\int_0^\pi sin\theta\ d\theta = \frac{2}{\pi} = 0.6366$$

RGGB structure with sub-pixel rendering has 0.72[cycle/pixel] space frequency at reference MTF level (0.6366). Its frequency is 1.44 times higher than 0.5[cycle/pixel] that is maximum frequency for RGB structure with normal pixel rendering. This is the result for horizontal direction but it is same 1.44 times higher for vertical direction because RGGB structure is same arrangement after 90 degree rotation and light control filter is circular symmetry. Therefore, total resolution is 〚1.44〛^2=2.1 times higher than conventional.

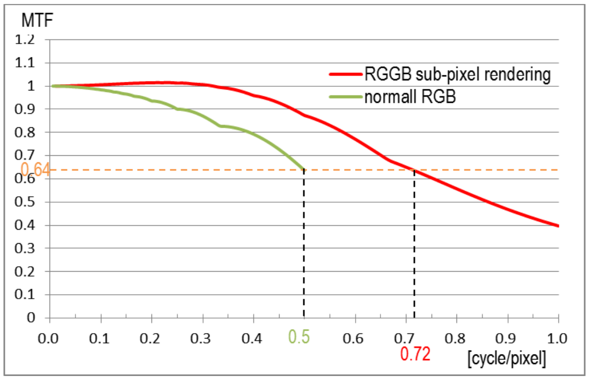

Fig.5 MTF for RGB with normal pixel rendering (green) and RGGB with filtered sub-pixel rendering (red)

4.2 Evaluation of perceptual resolution by visual test

A subjective evaluation has been conducted. That is viewing test comparing between RGB-PR and RGGB-FSR Figure.6 shows displaying pattern and test conditions. Displaying pattern is a wedge pattern which has continuous change of sine wave frequency. The vertical and horizontal patterns are prepared for horizontal and vertical resolution test. The wedge pattern changing from 0.1[cycle/pixel] to 0.5[cycle/pixel] is displayed on RGB display and another wedge pattern changing from 0.1[cycle/pixel] to 1.0[cycle/pixel] is displayed on RGGB display.

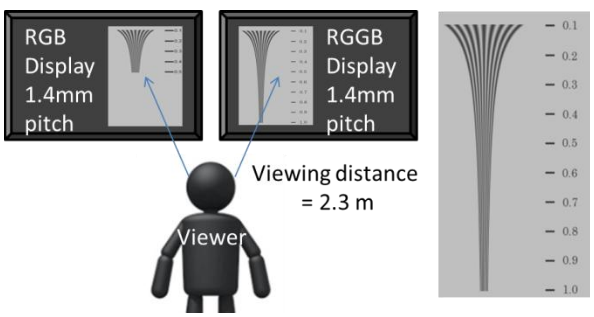

Fig.6. The way of practical evaluation and used wedge pattern

The different wedge patterns changed phase and amplitude of sine wave are used and average calculation is processed. Participants watch the wedge pattern on display and answer the maximum space frequency that bright and dark pattern are recognized.

Figure7 shows the score range and average for the test that participants are 10 people and pattern number is 9 with changing 3 phases and 3 amplitudes.

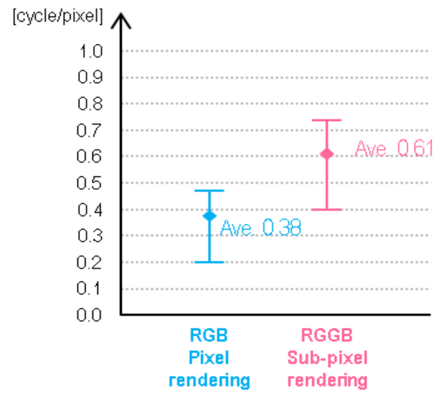

Fig.7. Score rage and average for visual test recognizing maximum space frequency in sine wave wedge pattern.

As a result, RGGB-FSR has about 1.59 times higher horizontal and vertical resolution than RGB-PR. Thus, the total resolution is about 2.5 times higher. The result is almost same with the evaluation calculated MTFs.

5. CONCLUSION

We have developed a new LED display that has RGGB sub-pixel structure with filtered sub-pixel rendering. The color fringe artifact has been reduced and perceptual resolution has been improved. We have defined a new method to compare perceptual resolution by calculated MTF using sine wave and evaluated out method. And it also has evaluated by visual test. It is sure to be about 2 times higher perceptual resolution than RGB structure with same pixel pitch. Thus, even if it is $1/\sqrt{2}$ pixel pitch, it is possible to produce same resolution displays. It cause 30% cost cutting due to reduction of LED chips.

References

[1] L. Fang, O. C. Au, K. Tang, and X. Wen Increasing image resolution on portable displays by subpixel rendering (APSIPA, 2012)

[2] Dean S. Messing and Louis J. Kerofsky USING OPTIMAL RENDERING TO VISUALLY MASK DEFECTIVE SUBPIXELS (SPIE-IS&T/ Vol. 6057 60570O-1)

[3] Suk-Ju Kang HSI-Based Color Error-Aware Subpixel Rendering Technique (JOURNAL OF DISPLAY TECHNOLOGY, VOL. 10, NO. 4, APRIL 2014)

[4] BAYER, B. E., 1976. Color imaging array, July. US Patentnumber 3971065.

[5] Kodak Lossless True Color Image Suite http://r0k.us/graphics/kodak/

Author Biography