Mixed Color Sequential Technique for Reducing Color Breakup and Motion Blur Effects

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Abstract

This paper proposes a mixed color sequential (MCS) algorithm with high contrast enhancement technique in RGB LED backlight display. Owing to synchronous control of LCD and LED panels, high quality image with suppressed color breakup and motion blur effects is achieved by our novel color sequential technique. Importantly, MCS algorithm is useful for color filter-less optical compensated bend (OCB) panel display for alleviating color breakup and motion blur effects. Furthermore, high contrast image is also presented on LCD panel because of mixed RGB and CMY backlights with optimum power consumption. In other words, MCS algorithm with high contrast enhancement technique can have the better performance compared with other field sequential color techniques. Experimental results demonstrate by an actual RGB backlight module for 32 inch 1366*768 LCD panel the improvement of color breakup and motion blur effects.

Keywords: Field sequential color, LCD, LED Backlight, Motion Blur, Color Breakup (CBU), Color Gamut, Image Quality, Optical Compensated Bend (OCB), color filter-less

1. Introduction

The choice of backlight can influence the performance of LCD display. White LED backlight has better color gamut than that of CCFL backlight. However, RGB LED backlight has the best color gamut, which is about 110% NTSC. The comparison of three popular backlight techniques is shown in Table 1. Thus, in order to have compatible NTSC color gamut, the technique of RGB LED backlight for improving the display performance is a trend of today’s LCD display market.

Table 1: Comparison between three backlight techniques of LCD.

<table>
<thead>
<tr>
<th></th>
<th>CCFL</th>
<th>White LED</th>
<th>RGB LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation</td>
<td>Medium</td>
<td>Poor</td>
<td>Better</td>
</tr>
<tr>
<td>Color Gamut</td>
<td>60% NTSC</td>
<td>70-80% NTSC</td>
<td>110% NTSC</td>
</tr>
<tr>
<td>Lighten</td>
<td>60-80lm/W</td>
<td>15-20lm/W</td>
<td>15-20lm/W</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Startup</td>
<td>Need warm-up</td>
<td>Not need warm-up</td>
<td>Not need warm-up</td>
</tr>
<tr>
<td>Life</td>
<td>Short</td>
<td>Long</td>
<td>Long</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Medium</td>
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</tr>
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</table>

Owing to high power consumption in RGB LED backlight, color sequential techniques are proposed to reduce the power consumption without sacrificing color gamut. Besides, a color breakup-less pattern is needed to reduce the side effect of color breakup [1]. In other words, we have to propose a novel color sequential technique not only to reduce the power consumption but also eliminate the color breakup.

As we know, it is very difficult to eliminate the motion blur in CCFL backlight technique because the flexibility of design CCFL backlight is low. However, for RGB backlight technique, the display method emulates impulse-type display compared to the hold-type display by CCFL backlight technique. Furthermore, it is very easy to insert black frames to eliminate motion blur effect for RGB backlight technique because of fast response of RGB LEDs.

In this paper, we propose a novel architecture to control the LCD and LED backlight, which is shown in Fig. 1. The architecture can simultaneously control the LCD and LED panels because (R, G, and B) image data is not only sent to gate and source driver controllers (GCON and SCON) but also to backlight controller (BCON). According to the (R, G, and B) image data sent to LCD controller, the strength of RGB backlight can synchronously respond to actual image data [2, 3, 4]. Color breakup and motion blur effects can be reduced by our mixed color sequential (MCS) algorithm because of synchronous backlight control. Our novel MCS algorithm with high contrast technique also enhances image quality. RGB backlight design architecture is shown in Fig. 2(a). Fig. 2(b) shows RGB backlight module for 32 inch LCD panel with resolution 1366*768. Fig. 2 (c) and (d) show the color sequential and control circuits pattern, respectively.

Color breakup and motion blur effects in conventional field sequential color display are explained in Section 2. Mixed color sequential algorithm and high contrast enhancement technique in Section 3. Section 4 presents experimental results and demonstrates the performance of MCS algorithm and high contrast enhancement technique. Furthermore, we also illustrate the high quality image can achieve optimum power consumption compared to conventional color sequential technique. Finally, we make a conclusion in Section 5.

Fig. 1: System architecture for our proposed novel mixed color sequential (MCS) algorithm.
2. Color breakup effects in conventional field sequential color display technique and motion blur effects in LCD display

A. Color Breakup effects

Owing to the separation of color fields, a image frame with different color fields, which located on different area of human retina, can not be viewed as a clear image with mixed color. The separation of different color fields is distinguished by human’s vision system from a mixed color image frame. As we know, this phenomenon is color breakup [5].

A moving object on FSC displays appears “rainbow effect” at the leading and tailing edges of the object. This effect named as “color breakup” (CBU) comes from sequential color techniques. Fig. 3 shows rainbow phenomenon caused by CBU effect. For a moving image, the sub-frames of moving objects are not plotted at the same spot for the smoothly moving retina. As a result, extra color fields are observed especially near the edges of the moving object. It is illustrated in Fig. 4 [6]. CBU is perceivable by vision systems where different sub-frame colors are observed separately. However, spatial and temporal variations can eliminate the CBU effect because smaller spatial division and higher temporal refresh rate can make human eyes fail to find rainbow effect. It means that high sub-frame rate and small spatial division improve the performance of color sequential technique.

B. Motion blur effects

The slow response time of liquid crystal and hold-type driving technique are the main reasons that incur motion blur effects [7, 8]. The panel designers focus on fast response time of liquid crystal material. However, it needs much time to develop good performance of liquid crystal. Thus, we can depend on the novel driving techniques to enhance image qualities with reduced motion blur effects.

For liquid crystal display technique, image brightness is determined by angle of liquid crystal not by backlight module with steady driving method. It means that the strength of backlight doesn’t depend on the content of image. However, the display technique provided by cathode ray tube (CRT) is named as impulse-type technique shown in Fig. 5(a) because focused beam of electrons generated by CRT excite phosphor layer with red, green, blue zones. Each pixel on the CRT screen is lightened owing to the excitation of focused beam of electrons. After excitation, material can come back to its initial status. It is very difficult for human’s vision system to find out the process of excitation during a short period as shown in Fig. 5(b) [9]. Contrarily, it is easy for human vision system to find out the blur effect by the hold-type display technique. In Fig. 6(a), the movement of square block by hold-type backlight technique has serious motion effect in Fig. 6(b).

3. Mixed Color Sequential Technique for RGB Backlight System

A. RGB color sequential technique

In traditional LCD display, CCFL always emits white light and the light passes the color filter to become R/G/B three colors. The effect results in Motion Blur and the high power consumption. We propose a novel color sequential technique in Fig. 7(a), which uses pseudo-random sequences of color in the spatial and temporal domain on the LCD.
In the spatial, we divide a LED panel to many blocks and sequentially display different colors like red, green, blue, or black on each block. Each LED frame is composed of four LED sub-frames. Therefore, the color sequence of each block in time domain is shown in Fig. 7 (b) and (c). Besides, in order to further reduce color breakup effect, we can add another type of four LED sub-frames as sub-frame 5 to 8 as shown in Fig. 7 (a). When displaying moving images, the rainbow effect still happened. But with the new technique, the eyeballs of human find different colors having breakup at the same time. That is we can’t see through exact color breakup when an object is moving. It means that this color sequential technique is successful to further suppress color breakup effect in the visual system according to human’s illusion.

As we know, if we want to implement this technique on color filter-less LCD panel, we must synchronously control the gray level of LCD panel. However, owing to slow response time of liquid crystal, we can only use four LED sub-frames in time domain. In other words, LED sub-frame rate is limited within 240Hz. Thus, spatial division for achieving small block size becomes another useful solution to alleviate color breakup effects. Conversely, the LED sub-frame rate in LCD panel with color filter is not limited within 240Hz. Thus, we can increase the number of LED sub-frame from four sub-frames, to sixteen sub-frames, or to sixty-four sub-frames because the control of LED backlight is not needed to be synchronized with that of LCD panel. It means that the probability of color breakup found by human’s eyes is small enough to achieve a high quality image. The iteration of color sequential technique is shown in Fig. 7(a). Higher sub-frame rate makes color breakup effect lower than that of conventional color sequential techniques. Furthermore, the operation of MCS color sequential technique is emulated as impulse type in temporal domain. That is why the motion blur effect can be suppressed.

B. **CMY color sequential technique**

60Hz

In order to have high luminance without sacrificing color gamut, we propose Cyan-Magenta-Yellow (CMY) color sequential technique in LCD panel with color filter in Fig. 8 (a) and (b) for high brightness [10]. This technique also uses pseudo-random sequence of color in the spatial and temporal domain on the LCD for eliminating CBU and motion blur effects.

As we know, if we want to implement this technique on color filter-less LCD panel, we must synchronously control the gray level of LCD panel. However, owing to slow response time of liquid crystal, we can only use four LED sub-frames in time domain. In other words, LED sub-frame rate is limited within 240Hz. Thus, spatial division for achieving small block size becomes another useful solution to alleviate color breakup effects. Conversely, the LED sub-frame rate in LCD panel with color filter is not limited within 240Hz. Thus, we can increase the number of LED sub-frame from four sub-frames, to sixteen sub-frames, or to sixty-four sub-frames because the control of LED backlight is not needed to be synchronized with that of LCD panel. It means that the probability of color breakup found by human’s eyes is small enough to achieve a high quality image. The iteration of color sequential technique is shown in Fig. 7(a). Higher sub-frame rate makes color breakup effect lower than that of conventional color sequential techniques. Furthermore, the operation of MCS color sequential technique is emulated as impulse type in temporal domain. That is why the motion blur effect can be suppressed.
are always two LEDs turned on among three RGB LEDs for every sub-frame. The luminance of CMY color sequential technique is raised and the effect of CBU is also reduced for displaying two of colors at the same time.

C. High Contrast Algorithm

In order to implement high contrast technique [11, 12] in our MCS algorithm in LCD panel with color filter, we raise LED sub-frame rate to display many complete sequences in one image frame period (1/60 sec). Thus, the combination of CMY sequence, RGB sequence, and black insertion can constitute different brightness degree for high contrast display, which is shown in Fig 9.

![Fig. 9. Combination of CMY sequence, RGB sequence, and black insertion.](image)

We combine two color sequential techniques to generate a low power high contrast backlight system. Generally speaking, the brightness of CMY color sequential technique is twice that of RGB color sequential technique. In other words, the combination RGB and CMY backlight can raise the image contrast. At first, we use a low resolution backlight panel to map to a high resolution LCD panel. It means that the backlight panel is designed as x*y regions to map to M*N regions in LCD panel. Thus, each individual block contains (M/x)*(N/y) pixels. The decision of mixed backlight is the average gray level value of block N. If we finish the average of the individual block, we can decide the backlight patterns in procedure 2.

In procedure 1, we use equation (1) to calculate the average gray level value of block N from step 1 to 4.

\[ V_N = \frac{1}{x} \sum_{n=1}^{N} \frac{P_n}{y} \]  

(1)

\( P_n \) stands for the gray level value of every pixel in block N. This procedure is finished when all gray level of every pixel in block N is averaged. Then, \( V_N \) stands for the average value of block N. If we finish the average of the individual block, we will decide the backlight patterns in procedure 2.

In step 6, we make sure the average gray level is equal to zero or not. If the average gray level is zero, the backlight is turned off in step 7A. For nonzero average gray level value, we can decide the backlight patterns by step 8A or 8B. If we turn on the ultra high contrast, the backlight patterns are decided by equations (2)-(4). Parameter \( F \) is LED sub-frame rate and equal to four times a LED frame rate because a LED frame is composed of four sub-frames. Parameters \( G \) and \( Z \) are the maximum gray level of liquid crystal and the minimum backlight value of RGB, respectively. Equation (2) makes the backlight panel have higher contrast when low average gray level values are smaller or equal to \( G/2 \). Based on minimum intensity of parameter \( Z \), the ratio \( V \) to \( G \) determines the combination of backlight sequence, which is shown in right-side graph of Fig. 9. In other words, we use RGB patterns decided by equation (2) and black data insertion [13, 14] to display such a low gray level. However, we use RGB and CMY patterns to get a high image quality for higher gray level display, which is shown in left-side graph of Fig. 9. Equations (3) and (4) determine the mixed RGB and CMY patterns for MCS technique.

\[ RGB_{\text{pattern}} = \text{ROUND}\left( \left( \frac{F}{4} - \frac{Z}{2} \right) \frac{2V}{G} + \frac{Z}{2}, 1 \right) \quad \text{for} \quad V_N \leq \frac{G}{2} \]  

(2)

\[ RGB_{\text{pattern}} = \text{ROUND}\left( \left( \frac{F}{4} - \frac{Z}{2} \right) \frac{V}{G} - \frac{Z}{2}, 1 \right) \quad \text{for} \quad V_N > \frac{G}{2} \]  

(3)

\[ CMY_{\text{pattern}} = \text{ROUND}\left( \left( \frac{F}{4} - \frac{2V}{G} \right), 1 \right) \quad \text{for} \quad V_N > \frac{G}{2} \]  

(4)

![Fig.10. Flow Chart for MCS algorithm with high contrast.](image)
\[ RGB_{\text{pattern}} = \text{ROUND} \left( \frac{F \times \left( 1 - \frac{F}{G} \right)}{4}, 1 \right) \]  

\[ CMY_{\text{pattern}} = \text{ROUND} \left( \frac{F \times \left( 1 - \frac{F}{G} \right)}{4}, 1 \right) \]  

Due to mixed RGB and CMY patterns, we can get a high contrast display on LCD panel. Using optimum power consumption displays a high contrast image. Besides, we use black data insertion in ultra high contrast technique. It makes the contrast of image larger than that of conventional color sequential technique. The advantage of our MCS algorithm with high contrast enhancement technique is high contrast performance with optimum power consumption.

D. MCS technique on Optical Compensated Bend Panel

Optical compensated bend panel utilizes special arrangement of liquid crystal molecules to implement angular compensation for good uniformity and wide view angle. Not similar to large switching liquid crystal on TN panel, OCB panel can have the same gray level with little switching liquid crystal under the same electric field. It means that OCB panel can have small response time.

Owing to four sub-frames provided by MCS technique, OCB panel without color filter needs to raise the sub-frame rate to about 240Hz. The absence of color filter on fast-response OCB panel means the synchronous data sequence for LCD driver and LED driver for correct color display. It means that MCS technique is suitable for color filter-less OCB panel by modifying the data sequences sent to LCD and LED drivers. For high contrast algorithm, we can’t raise the sub-frame rate because of limitation of OCB panel’s response time. In other words, spatial enhancement dominates the performance of OCB panel. In the future, the decreasing response time of liquid crystal can also improve the image quality due to temporal enhancement. Mixed spatial and temporal technique can have the best display performance.

4. Experimental results

A. RGB color sequential technique

It is obvious that RGB color sequential technique can improve color breakup effect compared to conventional color sequential technique because of spatial and temporal display technique. Experimental environment is: The rate of shutter is 1/25 second and the size of white square block is 36 pixels * 38 pixels. The moving speed of white square block from left-top to right-bottom is 240*(√2) pixel/s. In Fig. 11 (a), we can observe separate RGB square objects on LCD panel without color filter. It means that conventional color sequential technique suffers serious color breakup effect. The reason of serious color breakup effect is that it is very easy to find out color breakup effect for human’s eyes for separate RGB frames. It is the disadvantage of only temporal technique for solving color breakup effect. In other words, we have to adapt spatial technique to color sequential technique for improving the color breakup effect. Owing to mixed temporal and spatial color sequential technique, the illusion of mixed color sequence reduces the color breakup generated by color sequential technique. The improvement is shown in Fig. 11 (b). Generally speaking, mixed color breakup in every small area dexterously make human’s eyes hard to distinguish clear color from mixed color breakup.

In order to estimate the effects of motion blur, a white square object with black background moves from left-top to right-bottom on different panels, which are CRT panel, LCD panel with CCFL backlight module, and OCB LCD panel(color filterless panel) with RGB backlight module. According to the pictures taken by digital camera, we can observe that there is no motion effect on CRT panel because of impulse-type display technique, which is shown in Fig. 12 (a).

Owing to the different brightness between in red and green windows, we can observe obvious blur images in red window in Fig. 12 (b), which is estimated on LCD panel with CCFL backlight module. After the receiver of human’s eyes, it is easy to find out blur effect at the edge of white square object [15]. However, the blur effect can be alleviated by RGB color sequential technique implemented on OCB LCD panel (color
filterless panel) with RGB backlight module because of impulse-type display. The brightness of blur images in red window can be ignored by RGB color sequential technique in Fig. 12 (c), which shows the alleviation of blur effect. The blur effect is shrunk from a red window in Fig. 12 (b) to few blur pixels in red window in Fig. 12(c).

![Fig. 12. (a) Moving object on conventional CRT display. (b) Motion blur owing to moving object on liquid crystal display by CCFL hold-type backlight module. (c) Motion blur owing to moving object on liquid crystal display by RGB impulse-type backlight module.](image)

B. CMY color sequential technique

Owing to the absence of color is only one color in RGB backlight module by replacing RGB color sequential technique by CMY color sequential technique, the color breakup effect of CMY color sequential technique is less than that of RGB color sequential technique. The comparison between Fig. 13 and Fig. 11 (b) can illustrate the improvement benefited from CMY color sequential technique. Although, the improvement of motion blur by CMY color sequential technique is the same as that by RGB color sequential technique. It is obvious that the image quality is improved by CMY color sequential technique because of reduced blur effect, which is shown in Fig. 14, which implemented on OCB LCD panel (color filterless panel). As we expect, the blur effect in red window is better than that generated by RGB color sequential technique. However, the color gamut is lightly reduced because of OCB LCD panel.

![Fig. 13. Color breakup owing to CMY color sequential technique.](image)

![Fig. 14. Reduced blur effect in CMY color sequential technique compared to RGB color sequential technique.](image)

C. High Contrast Algorithm

The experimental color gamut of our RGB backlight is about 102.5% NTSC. The comparison of color gamut is shown in Fig. 15. As we expect, it is larger than that of CCFL backlight technique.

A photo in Fig. 16, which contains a sun with high brightness, is used to demonstrate the performance of MCS algorithm with OCB LCD panel (color filterless panel). It seems that the image with uniform RGB backlight doesn’t have high contrast only by gray level of LC. Conversely, the image with uniform and high power CMY backlight shows high brightness for whole image. However, the image contrast is not improved by uniform CMY backlight because of whole image with high brightness.
However, with our proposed high contrast technique, the sun has the highest brightness can be enhanced by CMY color sequential technique. The rest of the image is also enhanced by the calculation of gray level in each individual block. In other words, a high contrast enhancement technique can save much power consumption compared to the white LED backlight technique. Importantly, we use optimum power consumption to enhance the contrast of the image. High quality display can be achieved by our MCS algorithm with high contrast enhancement technique.

We point out the difference between three color sequential techniques by three square regions from Fig. 16 (a) to (c). Owing the highest brightness in Fig. 16(c), the details of gray level in red square region can’t be obvious for our eyes. However, for green square region, the sun can be expressed perfectly by Fig. 16 (b) and (c). Fig. 16 (a) can’t present a bright sun. Furthermore, owing to incremental brightness expressed by Fig. 16 (b), the details of blue square region can be displayed according to actual image gray level. It is the advantage of our MCS algorithm with high contrast enhancement technique.

Fig. 17 and Table II show the power consumption of four distinct blocks. It is obvious that high contrast enhancement technique is achieved by little increase in power compared to RGB color sequential technique.

5. Conclusions

Mixed color sequential algorithm with high contrast enhancement technique in RGB LED backlight display achieves high quality image with suppressed color breakup and motion blur effects. Furthermore, high contrast image with optimum power consumption is also presented in LCD panel because of mixed RGB and CMY backlights. In other words, MCS algorithm with high contrast enhancement technique can have the better performance compared with other field sequential color techniques. Furthermore, the mixed color sequential technique is still developed for color filter-less OCB panel. The optimum solution of mixed spatial and temporal technique will be achieved by our MCS technique.

![Fig. 15. CIE color chart.](image)

![Fig. 16. (a) Only RGB color sequential technique. (b) Combination RGB and CMY color sequential techniques. (c) Only CMY color sequential technique.](image)

![Fig. 17. Original image displayed by CCFL backlight.](image)

<table>
<thead>
<tr>
<th>Mode</th>
<th>RGB backlight</th>
<th>CMY backlight</th>
<th>MCS Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block1</td>
<td>2.484w</td>
<td>4.968w</td>
<td>3.260w</td>
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<tr>
<td>Block2</td>
<td>2.484w</td>
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<td>3.726w</td>
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<td>Block4</td>
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<tr>
<td>Average</td>
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Reference


