Development of Multi-Primary Color LCD

Chih-Cheng Chan, Guo-Feng Wei, Hui Chu-Ke, Sheng-Wen Cheng, Shih-Chang Chu, Ming-Sheng Lai, Arex Wang

AU Optronics, Science-Based Industrial Park, Hsin-Chu, Taiwan

Shmuel Roth, Oded Ben David, Moshe Ben Chorin, Dan Eliav, Ilan Ben David.

Genoa Color Technologies, Herzelia, Israel

Abstract

Multi-primary color (MPC) technology is used to achieve wide gamut color reproduction. In this paper, MPC technology is applied to liquid crystal display (LCD). 4-primary color and 5-primary color displays were created, with the percentage of NTSC and brightness better than conventional LCDs. Furthermore, the cost of MPC display is cheaper than the display with wide gamut LED backlight.

1. Introduction

Conventional image systems display images based on three primary colors (RGB). However, not all of the colors perceived by the human eyes can be obtained by mixing three primary colors. Therefore, MPC displays are essential if vivid color reproduction is to be achieved. The displays use more than three primaries to display a color, and provide a wide color gamut.

Recently, the studies of MPC display were introduced. The 4-primary color display was developed by Epson[1]. This display reproduces a gamut more than 100% of the NTSC gamut by using red, blue, yellowish green, and emerald green color filters. The application of MPC technology in projector was discussed by Genoa[2, 3, 4]. There are several types of wide gamut demonstrators that include 4, 5 and 6 primaries. The research of 6-primary color LCD was published by Samsung[5] and Mitsubishi[6].

In this paper, the MPC panels are created, and three types of MPC displays are compared. Besides, the panel design, color conversion algorithm, and the performance of MPC panel are described.

2. Panel Design

2.1 Color Filter and Backlight Unit

Choosing the primary colors of MPC is the starting point while designing a MPC panel. With concerning the white balance, maximum brightness, maximum color gamut, process capability and material selection of color filter and backlight unit, and etc., it is deliberate to select the primary colors properly. What should be mentioned is that while extending the maximum color gamut, NTSC ratio is often used to judge performance of color reproduction. However, this index can not correctly indicate how many real surface colors[7], known as "Pointer's gamut", can be covered. As shown in Figure 1, parts of the distribution of real surface colors, such as cyan, are out of the NTSC gamut in x-y plane. In addition, there are no any real surface colors locating at green region of NTSC gamut. Both Pointer's gamut coverage ratio and NTSC ratio should be taken into consideration to judge color performance of display. For example, NTSC ratio of LCD1 (99%) is smaller than that of LCD2 (107%) but color performance of LCD1 is better than that of LCD2 shown in Figure 1 because the Pointer's gamut coverage ratio of LCD1 (90.1%) is larger than that of LCD2 (86.6%). As a result, additional primary color should locate in the yellow or cyan region.

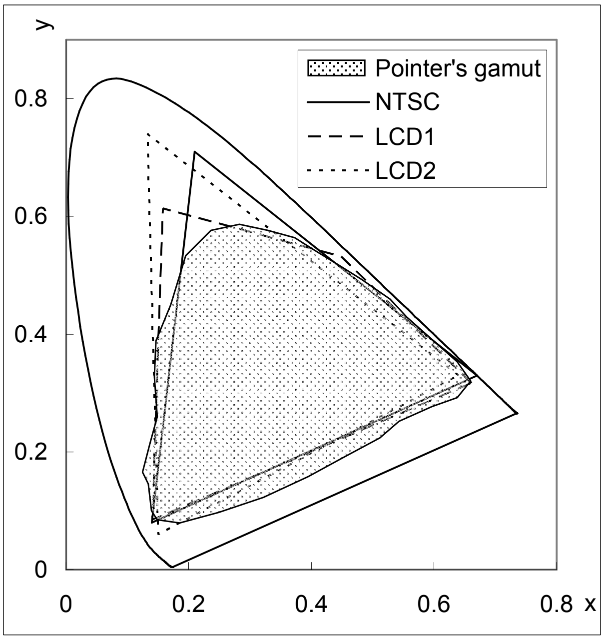

Figure 1. Different displays and Pointer's gamut in the CIE 1931 xy plane.

A simulation model is built to assist with deciding the primary colors. In this model, illuminant spectrum of a LCD panel is decided by several components and the formula can be shown as,

L(λ)=BL(λ)*C(λ)*CF(λ)

Where L(λ) is the illuminant spectrum of LCD panel, BL(λ) is the illuminant spectrum of backlight unit, C(λ) is the transmittance spectrum of LCD cell and CF(λ) is the transmittance spectrum of color filter. Then the chromaticity of each color of the LCD can be calculated from L(λ). According to experience, in real display, it is seldom to improve color reproduction by modifying C(λ). Therefore, color filter and backlight unit play important roles in color reproduction of LCDs. To get better color performance such as brightness and gamut coverage ratio, it is necessary to fine tune the transmittance spectrums of primary colors of color filter and illuminant spectrum of backlight unit.

The additional primary colors are yellow and cyan. The spectrum of yellow covers the wavelength range above 500nm and the spectrum of cyan covers the wavelength range from 400nm to 550nm. The transmittance spectrums of primary colors are shown in Figure 2. Regarding to the selection of backlight unit, to get higher NTSC ratio, conventionally RGB LED backlight unit are selected. However, this often increases cost of backlight unit. In this paper, the backlight unit only used the CCFL with modified phosphors. Although there are several newly developed phosphors could be used to increase NTSC ratio, such as red phosphor with emitting peak wavelength at 658nm, the decrease of emitting intensity impact the practicability. There is a trade-off between higher NTSC ratio and brightness while selecting phosphors. A compromise is made by mixing two or more phosphors. As a result, fine tuning the weighting ratio of phosphors can get higher NTSC ratio without losing much brightness of CCFL. In this circumstance, two kinds of CCFL with different spectrums are introduced. One is normal CCFL and the other is wide gamut CCFL, shown in Figure 3. From what has been discussed above, we have three prototype LCD panels: (1)RGBY with wide gamut CCFL (2)RGBYC with normal CCFL (3)RGBYC with wide gamut CCFL and noted as prototype No.1 and No.2 and No.3, respectively.

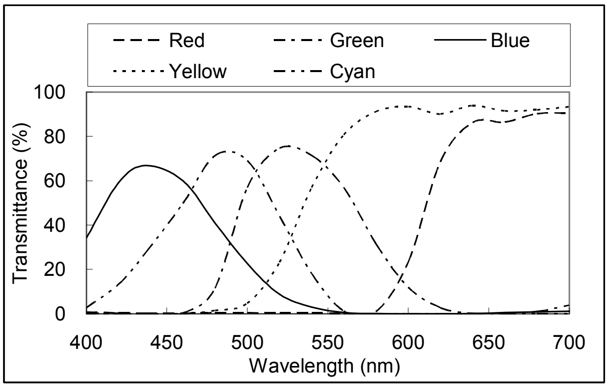

Figure 2. Transmittance spectrums of CF.

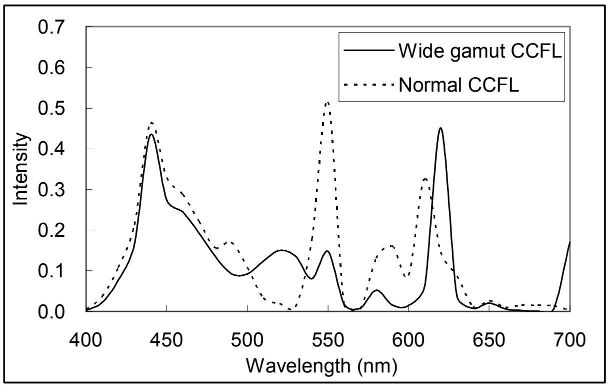

Figure 3. Illuminant spectrums of CCFL.

2.2 Array Layout and Primary Color Arrangement

There are several considerations for designing array layouts of MPC panel and the resolution is the first of all. Resolution can be classified into real resolution and perceptual resolution. Keeping the same real resolution as conventional means to add one or more sub-pixels in a pixel. However, two obvious side effects will be induced. One is the decrease of brightness resulted from the shrink of aperture area. The other is suffering additional cost resulted from the increase of the number of driver IC. Keeping the same sub-pixel size as conventional can get rid of the side effects discussed above. The perceptual resolution can be preserved by using the sub-pixel rendering technology. In this paper, the sub-pixel rendering technology, named as "Pixcale™", is developed by Genoa.

The display we report are based on a WXGA (1366 *768) backplane. Each raw has 1366*3 = 4098 sub-pixels, each of the sub-pixels with a 1:3 aspect ratio (so the RGB pixels are squares). The five primary color matrix is placed on this backplane. As a result, only 4098/5 ~ 820 "five primary color pixel" exist, with an aspect ratio of 5:3. This implies that any input data must be scaled in order to keep the image aspect ratio. However, if a scalar is applied before the MPC conversion, the input resolution of 1366*768 would reduce to 820*768 resulting in a loss of resolution. The Pixcale™ approach uses the same input resolution of the panel (namely 1366*768) and performs sub-pixel rendering algorithm at the MPC conversion unit output, where the five primary signals for each of the 1366 pixels in a raw is given. These signal are rendered on the sub-pixels according to the sub-pixel arrangement.

In contrast to RGB displays in which each color has a unique combination, multi-primary displays may reproduce the same color using several primary combinations. For example, yellow can be reproduced by the yellow sub-pixel and also by a combination of the red and green sub-pixels.

Similarly, cyan can also be reproduced by green and blue. By ordering the sub-pixels as RGBYC we create effectively, two yellow and cyan centers along each “five primary color pixel”. Also non-saturated colors may be reproduced by sets of three neighboring sub-pixels. The Pixcale™ approach uses that to reproduce yellow, cyan and non-saturated colors in higher resolution. Thus, the perceptual resolution is that of the input. In particular the luminance data can be fully reproduced. We note that for video input only the luminance should be reproduced at full resolution, since the chroma channels are sampled at half the luminance resolution. Furthermore, video data comes in a 720p format (1280*720) and its scaling into the native resolution of the panel (1366*768) also results in loss of high frequency content because of the anti-aliasing filtering.

2.3 Color Conversion Algorithm

Conventional displays contain RGB digital input signals. However, MPC displays contain more than three primary colors. Therefore, a color conversion algorithm is necessary to convert three-input signals to multi-input signals. Since RGB color space is device-dependent, all input signal should be transferred to a device-independent color space by a non-linear transformation followed by a characteristic matrix. Then the input color can be mapped to the expected color shown on the MPC display according to the shapes of gamut of RGB display and MPC display. After that, the color can be converted into multi-input signals by color conversion algorithm. The algorithm diagram is showed as Figure 4.

This structure of the algorithm is designed to give flexibility in the operation of the display. In contrast to RGB displays, in which the R input drives the red sub-pixel, there is no such relation in the multi-primary display. By placing an absolute color space as a reference, the input and output color gamuts become related. This has several advantages. The translation of the device dependent input data into absolute color data in the first step is parameterized, and thus using different sets of parameters we can control the required look of the display. This provides support for various modes of operation such as accurate standardized color on one hand (such as xvYCC support), or specific appealing display look on the other hand.

Furthermore, since the data is translated to absolute color space the mapping and multi-primary conversion unit may calculate the multi-primary signals based on the known gamut of the display. Thus, the algorithm can provide similar colors for similar inputs on displays with different color primaries. In order to provide support for different displays, the conversion unit assumes an ideal display, which is perfectly additive and with no dependence between the different color channels. The variation between displays is given by their physical display primaries.

The last unit is designed to match the behavior of a real display to the ideal behavior assumed by the conversion unit. This device dependent processing unit applies various corrections for the non-linear behavior of the displays, and other problems such as the dependence of one color channel on the other channels.

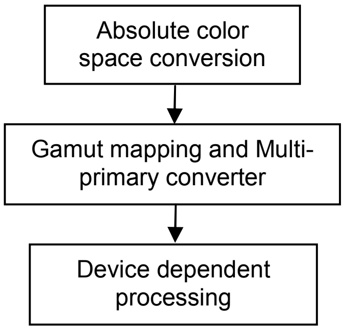

Figure 4. Color conversion algorithm diagram.

3. Performance of MPC Panel

The specifications and optical data of the three prototypes are listed in Table 1. As shown in Figure 5, the gamuts of these three prototypes all cover much more yellow and cyan colors than sRGB does, which results in high coverage of real surface colors. The images shown on these three prototypes all have much more excellent color performance than conventional RGB display. The prototype 2 has the best color performance at golden-yellow image such as gold and chrysanthemum. The prototype 3 has the best color performance at cyan and green image such as sky, ocean and grass. Although the color performance of prototype 1 is not the best at both yellow and cyan area but it takes lower CF cost than prototype 2 and 3 due to fewer process.

Table 1. Specification and optical data of 32” MPC display.

No.	1	2	3	
CF	4P	5P	5P	3P
CCFL*	W	N	W	
Resolution	1366*768			
NTSC(%)	95.3	91.4	109.9	72.1
Pointer’s gamut coverage ratio(%)	86.8	83.4	94.4	68.6
L (nits)	453	580	455	521

* “W” indicates wide gamut CCFL and “N” indicates normal CCFL.

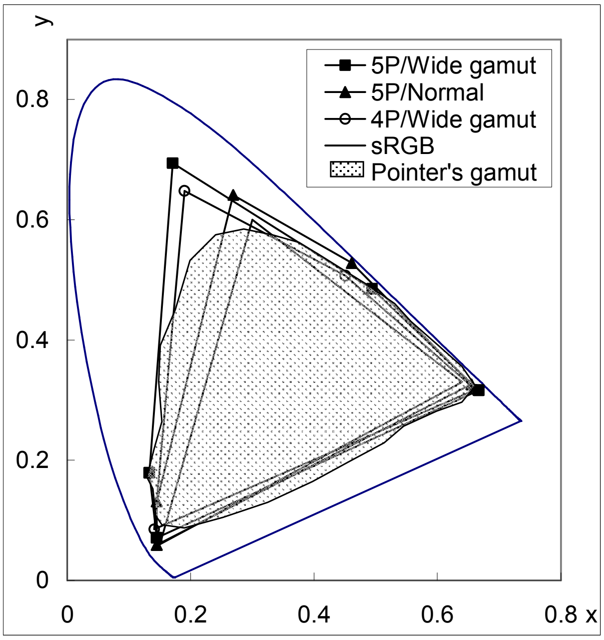

Figure 5. Gamut comparison of MPC panels.

4. Conclusion

In this paper, 4-primary color and 5-primary color displays are created. With the maximum NTSC ratio, the Pointer's gamut coverage ratio of 4- and 5-primary color LCD can achieve 86.8% and 94.4%, respectively. Furthermore, by selecting the CCFL backlight unit, the cost of MPC display is cheaper than the display with wide gamut LED backlight.

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