RGBW Transflective TFT LCDs with Adjustable Reflective Color Gamut by Image Processing Algorithm

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Abstract

Adjustable reflective color gamut RGBW transflective liquid crystal display (ARC RGBW TRLCD) applied simple manufacture process and image processing algorithm to achieve high brightness and good color performance both in transmissive and reflective mode. With appropriate modification higher transmittance but no color distortion happens in transmissive mode. Moreover, base on superior reflectance total brightness and color gamut also can be modified under different ambience. It provides the flexibility not only for any environments but also for variant personal hobbies. It is the best technique used both at indoor and outdoor.

1. Introduction

Due to the characteristics of thin profile and low power consumption, liquid crystal displays (LCDs) are widely used in electronic products such as cellular phones, digital cameras (DCs), personal digital assistants (PDAs), portable personal computers (PCs), projectors and the like. Generally, LCD panels are classified into transmisssive, reflective, and transflective types. Transmissive LCD panel uses a back-light module as its light source. Reflective LCD panel uses ambient light as its light source. A transflective LCD (TRLCD) panel makes use of both the back-light source and ambient light. Recently, LCDs fabricated in transflective structure have attracted great interest since their superior performance at both indoor and outdoor environments. TRLCDs make possible to obtain full bright and color by using ambient illumination as a light source. Only when ambient light is insufficient, internal light source can be used to supply enough brightness. Low power consumption does work. Since liquid crystal display technology has gradually replaced conventional cathode ray tube (CRT) technology, new pixel structures

are required to upgrade both brightness and color of liquid crystal panels to increase display quality. In conventional TRLCDs, each pixel is divided into transmissive and reflective area in order to have good image quality at various environments. Although various panels with high reflectance have been proposed and many solutions have been published before such as open-pinhole color filter, 6-peps with different color resister technique and so on to improve reflective brightness of TRLCD [1][2], color saturation decreases sharply and higher production cost compared with conventional TRLCD panel are all drawbacks not to be practicable. Hence, lots of problems still exist.

Recently, there were several papers to describe the application of RGBW sub-pixels system in transmissive LCDs in order to improve the brightness [3][4]. However, RGBW sub-pixels system also has some insufficient properties. The biggest cause is the absence of a proper RGB to RGBW mapping algorithm. Unsuitable image processing algorithm causes very serious image distortion compared with original image performance. Because of adding color white generally it changes the brightness but also decreases color saturation simultaneously. Although brightness increases, image looks fake. Displayed image seems to have poor contrast and faint colors.

Appropriate means preserving image quality, contrast ratio and color saturation, can overcome these obstacles. This paper provides a latest pixel structure combining an excellent method together for improving both brightness and color quality of TRLCDs. We have developed the transflective panel comprising

RGBW sub-pixels with variable transmissive and reflective area in order to achieve both

Figure 1

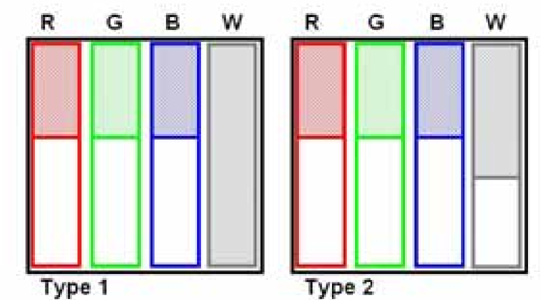

Figure 1 ARC RGBW TRCLD structure.

high transmittance and reflectance. Brightness of TRLCD can be improved by increasing the contribution of white sub-pixels therein but color saturation can not be affected by appropriate modification of image processing algorithm. Hence, the image can be full of brightness and vivid color. Moreover, image processing algorithms can transfer image data adjusted according to customer's versatile demands and variant ambient light. No comparable research has been provided for implanting RGBW sub-pixels system into transflective displays until now. We call this new structure adjustable reflective color gamut RGBW TRLCD (ARC RGBW TRLCD).

2. Structure

In ARC RGBW TRLCDs system, we add fourth sub-pixel with color white. On color filter glass substrate, there was just only overcoat and Indium Tin Oxide (ITO) on white sub-pixel regions. Besides that, RGBW structure is a natural extension of conventional RGB structure, such as RGB color resist and exposure parameter of exposure energy etc. By the same manufacture processes of conventional TRLCDs and appropriate image processing algorithm, ARC RGBW TRLCDs can modify a series of drawbacks. Image quality of RGBW pixel patterns can be better than traditional RGB pixel patterns having same number of pixels not only in brightness but also in color performance. Here, we introduce the ARC RGBW TRLCDs Type 1 and Type 2 as show in figure 1. The main characteristic of ARC RGBW TRCLD is able to control optical characteristics by adjustable reflective area of white sub-pixels. For example, ARC RGBW TRLCD Type 1 is a high-reflectance TRLCD. Because reflective area in white sub-pixels is 100%, reflectance can be optimized. Base on he same resolutions, reflective area compared with conventional RGB TRLCDs increases greatly. Hence, we can easily use Type 1 under outdoor environment without turning on back-light source even though ambient light is insufficient. Lower power consumption really happens because of turning on back-light source just only when there is no any ambient light. Moreover, in transmissive mode brightness and color saturation are not affected by white sub-pixels because of all white sub-pixels are blocked by reflective metal. The optical peroformance in transmissive mode can maintain as conventional RGB TRLCD. According this structure, we can keep original characteristics in transmissive mode and optimized brightness in reflective mode simultaneously.

ARC RGBW TRLCD Type 2 is a both high-transmittance and high-reflectance TRLCD. The reflective area of white sub-pixels is adjustable to be parts of transmittance and parts of reflectance. Hence, the contribution of white sub-pixels is not only in reflective but also in transmissive mode. Brightness in both transmissive and reflective mode can be enhanced. The proportion of brightness increasing in transmissive to reflective mode depends on the proportion of transmissive to reflective area in white sub-pixels. Consequently, in Type 2 we can use our structure to upgrade total brightness in transmissive mode and reflective mode at the same time. According to the issues mentioned above, image distortion is really serious after adding white sub-pixels. Especially in transmissive mode balanced color is a critical issue. Therefore, when adding white sub-pixels in transmissive mode, we have to make sure that total color performance is not affected too

Figure 2

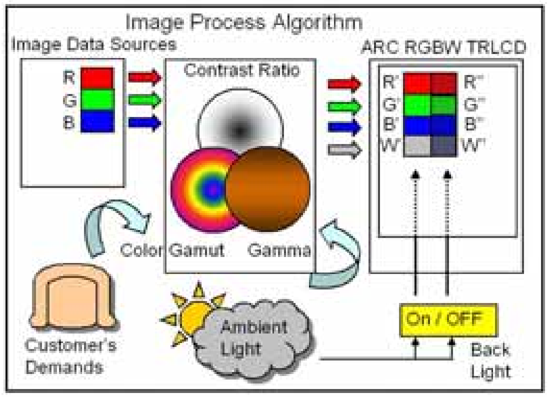

Figure 2 The block diagram of concept describing adjustable reflective color gamut.

much in transmissive mode. Using appropriate image process algorithm to harmonize color performance is necessary.

3. Algorithm

Figure 2 is the block diagram of concept describing adjustable reflective color gamut. Before showing image of picture on ARC RGBW TRLCD, RGB image data from original picture have to pass into image processing algorithm first to convert RGB to RGBW. This reproduction is to produce a revised image. RGB to RGBW conversion is the key procedure as mention above due to serious image distortion caused by white sub-pixels. Hence, only good image processing algorithm can perform the pictures better than conventional TRLCDs. In our algorithm, however, we can not only transfer RGB to RGBW in the best way but also modify total brightness, color saturation, gamma curve and contrast ratio simultaneously as we want to ensure that total image quality can be preserved. It is the feature for our algorithm to improve all drawbacks limited by fabrication at the same time. Besides that, according to different customer's demands or different country people's hobby we can advance to adjust hue performance base on their consideration. For example, some people rather like higher brightness, so we can just keep certain color saturation to upgrade brightness extremely. Contrary, in sufficient ambient light environment our panel can perform clear image naturally. We can show the image with more vivid color by our solutions. Hence, in different conditions of ambient light we also can use our image processing algorithm to let the image look more harmonic. Perfect RGBW images are performed in TRLCD by adjustable color reflective gamut.

In Type 1 case, when back-light source is on, same brightness and color gamut can be showed out compared with conventional TRLCDs because of useless white sub-pixels in transmissive mode. Special algorithm adjusting is not necessary. When back-light source is off, on the other hand, due to the contribution of white sub-pixel using our algorithms can optimize brightness and also keep certain color performance simultaneously. Adjustable gamma curve and contrast ratio can be fitted to make human vision more comfortable even though panels are just fabricated in single-gap structure. Similarly, in Type 2 algorithms can upgrade total performance and color saturation in transmissive and reflective mode. You also can adjust variant performance to meet different conditions. Moreover, in transmissive mode due to lots of brightness is contributed by white sub-pixels, unique algorithm is necessary to balance color. Brightness can increase obviously and also keep color saturation simultaneously when white sub-pixels adding in.

4. Characterization

Table 1 shows the characterization results of ARC RGBW TRLCD Type 1 using in different algorithms compared with conventional RGB TRLCDs using open-pinhole color filter in reflective mode. In

Table 1

ARC RGBW TRLCD Type 1 Structure					Ref.
Algorithm Type		A1	A2	A3	
Trans. Mode	T	4.3%			5.0%
	T-NTSC	42.1%			39.0%
Refl. Mode	R	8.3%			5.6%
	R-NTSC	18.4%	8.7%	4.1%	5.0%

Table 1 The characterization results of ARC RGBW TRLCD Type 1 with different algorithms compared with conventional RGB TRLCD.

Figure 3

Type 1 **RGB**

Figure 3 The comparison between ARC RGBW TRLCD Type using Algorithm 2 and conventional RGB TRLCD using open-pinhole color filter in reflective mode.

Type 1, reflectivity is larger than any conventional RGB TRLCDs due to totally reflective area of white sub-pixels. According to the characterization results, reflectivity is improved drastically. Increasing ratio of reflectance is high to 148% and 8.3% reflectance is the outstanding value until now. Base on the same reflectivity, NTSC value in different algorithm can be adjusted smoothly from 18.7%, 8.7% to 4.1% to meet different conditions. Figure 3 is the comparison between ARC RGBW TRLCD T1 using algorithm 2 and conventional RGB TRLCD using open-pinhole color filter in reflective mode. In algorithm 2, base on the same reflectance, 8.3%, higher NTSC value in reflective mode may sacrifice few brightness in some special images, however, vivid color can be better than the panel using open-pinhole color filter technique. Pale images when using open-pinhole color filter can not appear anymore. In algorithm 3, additionally, keeping certain NTSC value, 4.1%, our algorithm can modify total brightness extremely. Much power saving in parts of environments does work. In transmissive mode, no matter transmittance or NTSC value, our structure all can achieve almost the same level compared with conventional RGB TRLCDs when using any algorithms. No color shift happens in transmissive mode. It is the advantage for Type 1 that keeping the same performance in transmissive mode and adjustable high brightness and high color saturation in reflective mode does work. Same manufacture process, lower power comsumption but better optical performance in reflective mode is applied. The application of ARC RGBW TRLCD Type 2 can be different from Type 1. In type 2 not only reflectance but also transmittance are increased due to the contribution of white sub-pixels. Both transmissive and reflective brightness can be bigger compared with conventional TRLCDs. Table 2 shows the characterization results of ARC RGBW TRLCD Type 2. Total brightness in both transmissive and reflective mode can be upgrade. Increasing ratio of transmittance

Table 2

ARC RGBW TRLCD Type 2 Structure					Ref.
Algorithm Type		A1	A2	A3	
Trans. Mode	T	6.3%			5.0%
	T-NTSC	39.0%	30.1%	22.9%	39.0%
Refl. Mode	R	6.0%			5.6%
	R-NTSC	31.6%	16.2%	8.2%	5.0%

Table 2 The characterization results of ARC RGBW TRLCD Type 2 with different algorithms compared with conventional RGB TRLCD.

Figure 4

Type 2 **RGB**

Figure 4 The comparison between ARC RGBW TRCLD Type 2 using Algorithm 1 and conventional RGB TRCLD both in transmissive mode.

and reflectance is about 26% and 62% respectively. Fig. 4 shows the comparison between ARC RGBW TRCLD Type 2 using algorithm 2 and conventional RGB TRCLD both in tramsmissive mode. Although transmittance is high to 6.3%, NTSC value still maintain at 39.0% by appropriate modification such as algorithm 1. This algorithm is almost not to affect color saturation too much although total brightness is enhanced by white sub-pixels obviously. Average color shift (ΔE) is less than 0.02. Well defined image processing algorithms can let RGBW sub-pixels system develop better performance in transmissive mode. In reflective mode, although smaller reflective area in white sub-pixels may not increase brightness as large as Type 1, reflectance of Type 2 is still high to 6.0%. Both high transmittance, 6.3%, and reflectance, 6.0%, of ARC RGBW TRLCD is leading general TRLCDs and make human vision more enjoyable. Larger NTSC values in reflective mode can be showed out by different algorithms in Type 2, from 31.6%, 16.2% to 8.2%. It can be satisfy different people who ask for strong color critically. The advantage of ARC RGBW TRLCD Type 2 is that brightness both in transmissive and reflective mode is enhanced but no color shift happens. Especially in transmissive mode, using appropriate structure and algorithm make RGBW pixels structure to develop the biggest efficiency. No matter back-light source turns on or not, higher brightness compared with conventional RGB TRLCDs can let image be more readable. Different color saturation is also optional in Type2. By special structure with appropriate algorithm it makes open ratio increase and total optical performance upgrade drastically in the easy way.

5. Expectation

We also can use our technique to implant in low temperature poly-silicon (LTPS). Due to more spaces of gate line source are saved on the panel, there are more capacities to implant more different ideal algorithms in it. Hence, in the near future, we can design a Smart ARC RGBW TRLCD to satisfy versatile personal requirements. Base on personal prefer, they have more selections to play their LCDs such as different color background and so on. The Smart ARC RGBW TRLCD must be the trend of sunlight readable LCD in the near future.

6. Conclusion

Use the same manufacture processing and simple image processing algorithms in ARC RGBW TRLCD can be satisfy versatile demands no matter different environments or personal hobbies. By adjustable reflective area of white sub-pixels high reflectance, 8.3%, and good color saturation, NTSC 42.1%, are practicable in reflective mode. In transmissive mode, higher transmittance, 6.3%, but no color distortion happens, $\Delta E<0.02$. Hence, ARC RGBW TRLCD is the best solution applied in both indoor and outdoor to achieve high brightness and color performance but low cost and low power consumption simultaneously.

7. References

[1] DIGEST, 53.3
[2] Kohichi Fujimori, Kozo Narutaki Itoh, aofumi Kimura, Shigeaki Mizushima, Yutaka Ishii, Masaya Hijikigawa, SID 2002A
[3] Baek-woon Lee, Cheolwoo Park, Sangil Kim, Taehwan Kim, Youngchol Yang, Joonhak Oh, Jeongye Choi, Munpyo Hong, Dongsik Sakong, and Kyuha Chung, SID 03 DIGEST, 40.5L
[4] Michael E. Miller, Michael J. Murdoch, Paul J. Kane, and Andrew D. Arnold, SID 05 DIGEST, P-34