DES5-2
Invited

Analysis on a Three-dimensional Local Dimming Backlight

Liwen Deng [1], Ju Guo[1], Enguo Chen[1,2,*], Sheng Xu[1,2], Yun Ye[1,2], Qun Yan[1,2], Tailiang Guo[1,2]

*Corresponding author: ceg@fzu.edu.cn
[1]National & Local United Engineer Laboratory of Flat Panel Display Technology, Fuzhou University, Fuzhou, Fujian, China,350116
[2]Fujian Science & Technology Innovation Laboratory for Optoelectronic Information of China, Fuzhou, Fujian, China,350005

Keywords: Local dimming; Light guiding plate; Mini-LED; Backlight; Theoretical model.

ABSTRACT

This paper analyzes the performance of a pixel-level three-dimensional local dimming backlight unit. The illuminance distribution function based on the double-layered structure is derived and simulated by using MATLAB. A 5-inch LCD screen is tested, and the dark brightness and contrast of the single-layered structure and the double-layered structure are compared.

1 Introduction

At present, the exploration of liquid crystal display is increasing, in which the backlight module is very important for display luminescence. At the same time, with the emergence of new technologies, such as mini-LED and micro-LED, designing a backlight module with a novel structure has become a research hotspot [1-3].

Current dominant display technologies are liquid crystal display (LCD)[4] and organic light emitting diode display (OLED)[5]. These two display technologies are widely used in various display devices, but they have certain advantages and disadvantages[6]. For example, the main advantages of LCD are long lifetime, high peak brightness, and low cost. The remarkable feature of OLED is high ambient contrast, which can realize pure black [7]. Ultra-thin and flexible display can be easily realized by OLED. They are comparable in color gamut[8], screen resolution, dynamic response time[9], and power consumption. However, LCD has two important disadvantages: one is limited contrast ratio (CR: 1000-5000:1), and the other is weak flexibility. On the other hand, the main problem of OLEDs is that the lifetime will be affected with the brightness increase[10-11]. While referring to the high dynamic range technology (HDR)[12], LCD has the characteristics of high brightness, but lacks true dark state, while OLED is just the opposite [13].

In recent years, mini-LED and micro-LED displays[14-16] have attracted extensive attention because of their high dynamic range, high ambient contrast ratio [17] (ACR), and low power consumption [18-20]. For example, when mini-LED array is applied to the backlight module of liquid crystal display, the local dimming technology [21-27] can improve the CR of the display panel to 1000000:1 [28]. The self-luminous mini / micro-LED display will show a dark state with high authenticity, and the peak brightness is several times that of LCD and OLED displays [29].

This paper studies the optical performance of three-dimensional local dimming backlight unit, and systematically verifies the feasibility of the structure via simulation and experiment.

2 Theoretical Analysis

The schematic of a three-dimensional local dimming backlight is drawn and shown in Fig. 1.

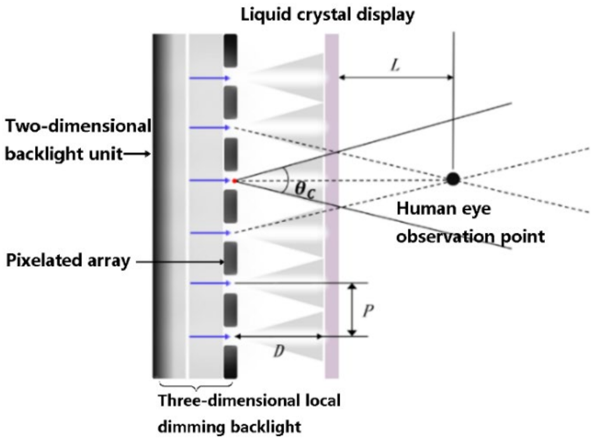

Fig. 1. Schematic of a three-dimensional local dimming backlight.

According to the theoretical analysis of three-dimensional area dimming, we can preliminarily deduce the illumination distribution of LCD at human eyes as follows:

$$E_i\left(\theta_i, l_i\right)=\frac{I_0 \cos\left(\frac{1}{2RD}\right)}{\left(D+L_i\right)^2+\left(\frac{1}{R}\right)^2} \tag{1}$$

where R is the resolution of the backlight unit. D is the spatial distance between the pixel array and the LCD panel. L is the distance between the display and the human eye.

3 Simulation

The illumination at the human eye is not only related to the resolution, but also related to the spatial distance between the LCD and the human eye. The illuminance of any point in the space is the superposition of the illuminance at that point. By using MATLAB, the internal relationship between the illuminance of any point and various factors in the three-dimensional local dimming theoretical model can be obtained, in which the illuminance of any point in the space is directly proportional to the resolution of the LC screen, and inversely proportional to the spatial distance. Next, Solidworks is used to model and design the double-layered structure. As shown in Fig. 2(a), the material property of the 9-pixel array is PMMA, and the optical properties of each element of the double-layer structure are set in TracePro shown in Fig. 2(b). Then, ray tracing is performed after setting the pixelated array with different resolution size in the simulation model.

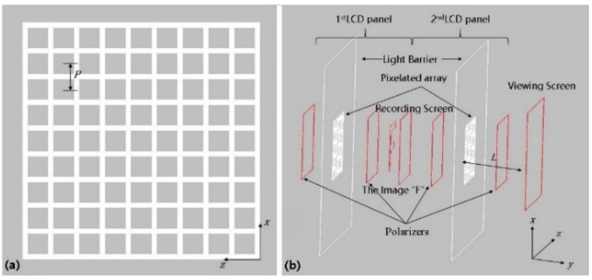

Fig. 2. (a) Pixel array model; (b) Double-layered structure based on a three-dimensional local dimming backlight.

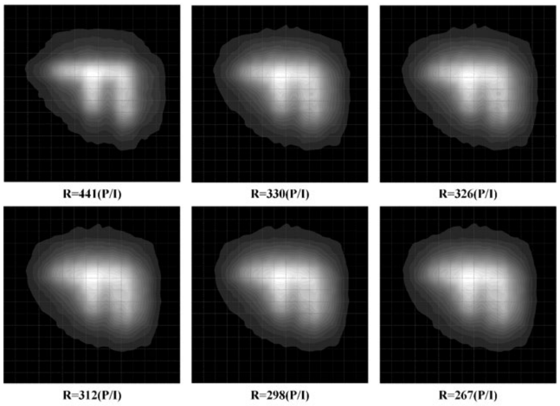

Fig. 3. Reconstruction diagram of the pixel array based on the three-dimensional local dimming backlight.

The influence of different resolutions on the luminous intensity of the double-layer structure is studied. The resolution of the pixelated array is defined by r = 441 (P / I), where r is the resolution of the LC screen, P is the total pixel number, and I is the screen size. The reconstructed image "F" collected from the receiving surface has a higher degree of clarity, and the reconstructed image, that is luminous letter "F", can be obviously seen. However, there is a certain halo contour area around the luminous letter "F".

4 Simulation Results

Different from two-dimensional local dimming, three-dimensional local dimming technology has light intensity distribution existing in the normal direction of two planes, corresponding to the left and right eyes of human eyes, respectively. This paper selects the optical characteristics of the right eye and calculates the relationship curve between the output light intensity and the observation angle under different resolutions. As shown in Fig. 4, it can be found that the peak intensity of the outgoing light intensity is stable near the observation angle of 90º with the resolution decrease, and the fluctuation range is within - 0.00011 ~ + 0.00021. The outgoing light intensity is distributed around ± 90º, and its fluctuation range is within 60º ~ 120º, indicating that most of the light energy is concentrated in the normal direction of the exit surface corresponding to the eye.

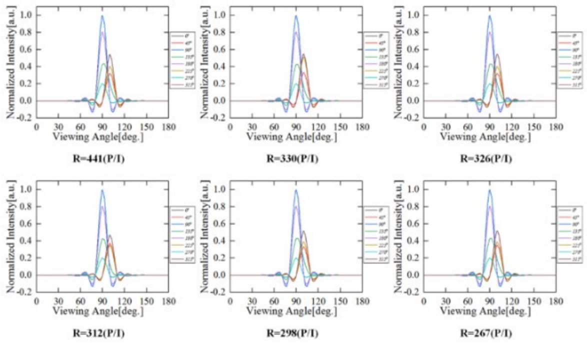

Fig. 4. Outgoing light intensity distribution at different resolutions.

The relationship between the spatial distance and the light intensity is studied by changing the spatial distance. As shown in Fig. 4, the spatial distance continues to increase which makes the luminous letter "F" unclear. Therefore, the spatial distance between the screen and the human eye has a certain threshold, beyond which the image cannot be displayed normally. Within the range of the spatial distance threshold, the image can be displayed normally and the sharpness needs iterative optimization.

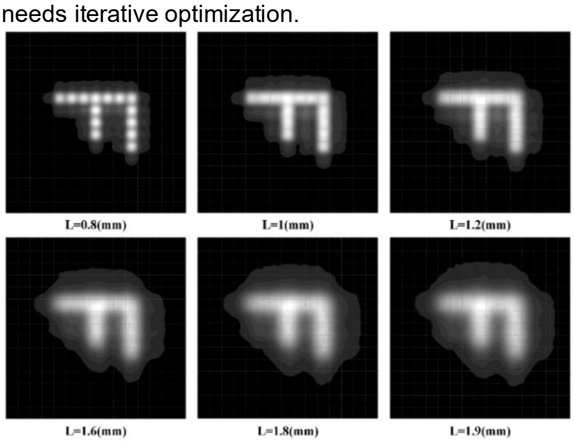

Fig. 5. Irradiance distribution at different spatial distances based on the three-dimensional local dimming backlight.

Under the conditions of different spatial distances, the outgoing light intensity distribution of the double-layered structure is shown in Fig. 5. The ray-tracing simulation results show that when the observation angle is 45º, the peak intensity of the outgoing light intensity is stable at about ± 80º. The fluctuation range of the outgoing light intensity distribution is within 60º ~ 90º, which increases with the spatial distance. The peak intensity of the outgoing light intensity has a slight deviation, and the error range is ± 0.000103. When the observation angle is expanded to 135º, the peak intensity of the outgoing light intensity first decreases and then increases with the increase of the spatial distance. The relative light intensity decreases from 0.6 to 0.3, and then increases back to 0.6, and the relative light intensity decreases to the minimum at the spatial distance of 1.9 mm. When the observation angle continues to expand to 225º, the relative light intensity changes from 0.3 to 0.5 with the increase of spatial distance, and the peak intensity position of the outgoing light intensity shifts significantly. When the observation angle is expanded to 315º, the variation range of relative light intensity is 0.4 ~ 0.8, the peak intensity of outgoing light intensity does not shift significantly, and the minimum value of outgoing relative light intensity is 1 mm in spatial distance. Compared with the light intensity distribution range of resolution, the observation angle has a more obvious impact on the light intensity distribution range of the double-layer structure.

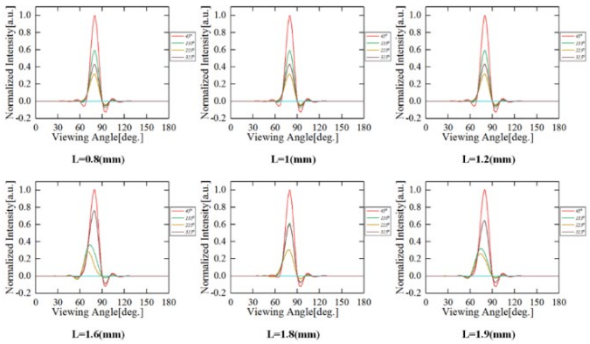

Fig. 6. Outgoing light intensity distribution at different spatial distances.

5 Performance Test

Based on the above analysis, an HDMI cable was used to connect a computer to the double-layered backlight module, and the initial image was displayed on a 5-inch (800×480) LCD screen, as shown in Fig. 7. The initial experimental image was selected as a burning "candle" with high contrast to show the dimming ability of the three-dimensional local dimming backlight. Combining the previous theoretical analysis and simulation results, the brightness tests of the single-layered and the double-layered backlight module were carried out. From the human subjective evaluation, the overall image brightness fell due to the double-layered LC panel. However, the main part of the "candle" displayed accurately, and the dark state area was very pure. It means that the display contrast ratio is high that can show more exquisite details.

The intermediate point of the "candle" flame is selected as the brightness test point, and the photometer and its supporting tripod are placed at a certain distance from the experimental backlight module to build an experimental test system. During the test, the temperature range is 25±2℃, the humidity range is 55 ±20%RH, and the illumination is less than 1 lux in a dark room environment. The distance is adjusted between the luminance meter and the experimental backlight module to test the luminance of the target point.

6 Conclusion

The backlight unit based on a double-layered structure shows higher picture fineness, wherein the double-layered LC layer plays an important role in the pixel-level three-dimensional local dimming. However, the backlight unit of the pixel-level three-dimensional local dimming technology tested in the experiment has a relatively low brightness. In order to promote the development of three-dimensional local dimming technology at pixel level, it is necessary to optimize the structure of three-dimensional local dimming which can control the transmittance separately (dimmable) and can be pixelated from the aspects of material and device structure.

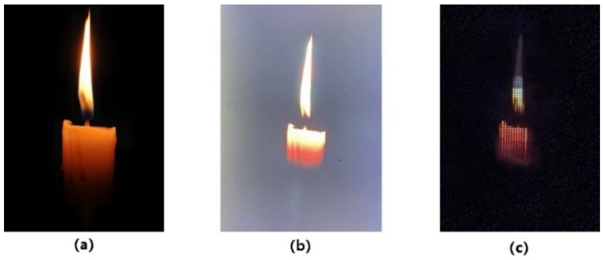

Fig. 7. (a) The original image; (b) Image displayed by the single-layered structure; (c) Image displayed by the double-layered structure.

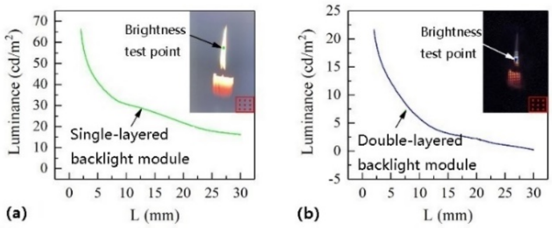

Fig. 8. (a) Brightness variation curve of single-layered backlight module; (b) Brightness variation curve of double-layered backlight module.

Acknowledgments

The authors would like to extend sincere gratitude to colleagues of Top Victory Electronics (Fujian) Co., Ltd and Malata (Zhangzhou) Co., Ltd for their assistance on this thesis. This work was supported by National Natural Science Foundation of China (Application No. 6217030331, Grant No. 61405037); Fujian Science and

Technology Key Project (2020H4021); Fuzhou Key Scientific and Technological Project (2020-Z-14); Project from Mindu Innovation Laboratory (2020ZZ111).

References

[1]. Jeongmin M, Kyunghwan O. Effects of Light-Emitting Diode（LED）Configuration on Luminance and Color of an Edge-Lit Backlight Unit[J]. Journal of Display Technology, 2015, 11(9):768-775.
[2]. Wu S-T. Next generation LCD technology [J]. Journal of Information Display, 2016, 26(1):3.
[3]. Schadt M. Milestone in the history of field-effect liquid crystal displays and materials[J]. Japanese Journal Applied Physics, 2009, 48:03B001.
[4]. Tang C-W, Vanslyke S-A. Organic electroluminescent diodes[J]. Applied Physics Letters, 1987, 51:913–915.
[5]. Chen H-W, Lee J-H, Lin B-Y, et al. Liquid crystal display and organic light-emitting diode display: present status and future perspectives[J]. Light-Science & Applications, 2018, 7:17168.
[6]. Tan G, Zhu R, Tsai Y, et al. High ambient contrast ratio OLED and QLED without a circular polarizer[J]. Journal of Physics D-applied Physics, 2016, 49:315101.
[7]. Zhu R, Luo Z, Chen H, et al. Realizing Rec. 2020 color gamut with quantum dot displays. Optics Express, 2015, 23(18):23680–23693.
[8]. Peng F, Chen H, Gou F, et al. Analytical equation for the motion picture response time of display devices[J]. Journal of Applied Physics, 2017, 121(2):023108.
[9]. Féry C, Racine B, Vaufrey D, et al. Physical mechanism responsible for the stretched exponential decay behavior of aging organic light-emitting diodes[J]. Applied Physics Letters, 2005, 87(21):213502.
[10]. Murawski C, Leo K, Gather M-C. Efficiency roll-off in organic light-emitting diodes[J]. Advanced Materials, 2013, 25:6801–6827.
[11]. Daly S, Kunkel T, Sun X, et al. Viewer preferences for shadow, diffuse, specular, and emissive luminance limits of high dynamic range displays[J]. SID Symposium Digest of Technical Papers, 2013, 44(1):563–566.
[12]. Park S, Xiong Y, Kim R, et al. Printed assemblies of inorganic light-emitting diodes for deformable and semitransparent displays[J]. Science, 2009, 325(5943):977–981.
[13]. Chen H, Tan G, Wu S-T. Ambient contrast ratio of LCDs and OLED displays[J]. Optics Express, 2017, 25(26):33643–33656.
[14]. Jiang H-X, Lin J-Y. Nitride Micro-LEDs and beyond a decade progress review[J]. Optics Express, 2013, 21(S3):A475–A484.
[15]. Templier F. GaN-based emissive Micro-displays: A very promising technology for compact, ultra-high brightness display systems[J]. Journal of the Society for Information Display, 2017, 24(11):669-675.
[16]. Tan G, Huang Y, Li M-C, et al. High dynamic range liquid crystal displays with a Mini-LED backlight[J]. Optics Express, 2018, 26(13):16572–16584.
[17]. Shirai T, Shimizukawa S, Shiga T, et al. RGB-LED backlights for LCD-TVs with 0D, 1D, and 2D adaptive dimming[J]. SID Symposium Digest of Technical Papers, 2006, 37(1):1520–1523.
[18]. Hulze H-G, Greef P-D. Power savings by local dimming on a LCD panel with side lit backlight[J]. SID Symposium Digest of Technical Papers, 2009, 40(1):749–752.
[19]. Bonar J-R, Valentine G-J, Gong Z, et al. High-brightness low-power consumption Micro-LED arrays[J]. Proceedings of The International Society for Optical Engineering, 2016, 9768:97680Y.
[20]. Seetzen H, Whitehead L-A, Ward G. A high dynamic range display using low and high resolution modulators[J]. SID Symposium Digest of Technical Papers, 2003, 34(1):1450–1453.
[21]. Seetzen H, Heidrich W, Stuerzlinger W, et al. High dynamic range display systems[J]. ACM Transactions on Graphics, 2004, 23(3):760–768.
[22]. Greef P-D, Hulze H-G, Adaptive dimming and boosting backlight for LCD-TV systems[J]. SID Symposium Digest of Technical Papers, 2007, 38(1):1332–1335.
[23]. Lin F, Huang Y, Liao L, et al. Dynamic backlight gamma on high dynamic range LCD TVs[J]. Journal of Display Technology. 2008, 4(2):139–146.
[24]. Chen H, Ha T-H, Sung J-H, et al. Evaluation of LCD local-dimming-backlight system[J]. Journal of the Society for Information Display, 2010, 18(1):57–65.
[25]. Kim S, An J-Y, Hong J-J, et al. How to reduce light leakage and clipping in local-dimming liquid-crystal displays[J]. Journal of the Optical Society of America A-optics Image Science and Vision, 2009, 17(12):1051–1057.
[26]. Burini N, Nadernejad E, Korhonen J, et al. Modeling power-constrained optimal backlight dimming for color displays[J]. Journal of Display Technology, 2013, 9(8):656–665.
[27]. Deng Z, Zheng B, Zheng J, et al. High dynamic range incell LCD with excellent performance[J]. SID Symposium Digest of Technical Papers, 2018, 49(1):996–998.
[28]. Day J, Li J, Lie D-Y-C, et al. III-Nitride full-scale high-resolution Microdisplays[J]. Applied Physics Letters, 2011, 99:031116.
[29]. Henry W, Percival C. ILED displays: next generation display technology[J]. SID Symposium Digest of Technical Papers, 2016, 47:747–750.