Perceptual Artifacts on the Liquid Crystal Displays with a Mini-LED Backlight

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Keywords: Artifacts; mini-LED backlight; local dimming; perception; human factor

Abstract

The halo artifacts on the liquid crystal displays with a mini-LED backlight needs to be reduced to an invisible level to achieve a better high dynamic range display system. The evaluation model and visibility threshold of the artifacts are established and investigated respectively through systematic perception experiments.

1. Introduction

For the display of the next generation, high dynamic range (HDR) plays an important role on viewing experience improvement.[1] To achieve HDR, the contrast ratio (CR) of the display system much reaches 10^5:1 and the peak luminance should be at least 1000cd/m^2. As the currently dominant technologies, liquid crystal display (LCD) and organic light emitting diode (OLED) both have their own problems to achieve the above HDR rendering required conditions. The contrast ratio of the normal LCD is only around 1000:1 to 5000:1, while OLED will compromise the lifetime to improve peak luminance. LCD with a mini-LED (light emitting diode) backlight is emerging as a qualified candidate for HDR image rendering.[2]

The LCD with a mini-LED backlight works with the locally pixel-compensated backlight dimming system. The system combines backlight modulation and pixel value compensation for eliminating light leakage while keeping the whole image at the original luminance level.[3] The mini-LED backlight is modulated with certain algorithm applied to the input image. The LCD panel is manipulated with liquid crystal (LC) pixel compensation of the input image. Due to one local dimming unit covers many LC pixels and the light leakage of the LC, the halo effect appears. The other perceptual artifacts happened in the opposite way, which is called the clipping effect.[2] These perceptual artifacts need to be reduced to an invisible level to achieve the HDR image rendering without image quality degradation in the other aspects.

The evaluation of the perceptual artifacts is important for improving the performance of the display system. Tan *et al.* proposed a quantitative halo effect evaluation metric using Peak Signal-to-Noise Ratio (PSNR) in the CIE 1976 $L^*a^*b^*$ color space.[4] The proposed metric is image content dependent and cannot be used to evaluate the display system directly. The perceptual artifacts on the LCD with a mini-LED backlight is similar to the crosstalk phenomenon[5] on the stereoscopic displays, and the evaluation should be focused on the display system itself. The viewing angle (VA) of one local dimming unit and CR of the LC panel are the main factors affecting the artifacts' visibility. In this paper, we investigated the perceptual artifacts on the LCD with a mini-LED backlight through two perceptual experiments. One experiment simply employs the square as one local dimming unit for visibility level scoring, and the other experiment using natural image for threshold testing.

2. Model of LCD with a Mini-LED backlight

2.1. Model establishment

The imaging simulation model of the LCD with a mini-LED backlight is established, and the basic procedure is shown in Fig. 1. With various choices of local dimming algorithms, the "maximum" method is used. The applied algorithm is simple without other artifacts besides the halo effect. The backlight unit employs the maximum value of the pixels within the unit. The Gaussian distribution is used to simulate the single mini-LED light profile.

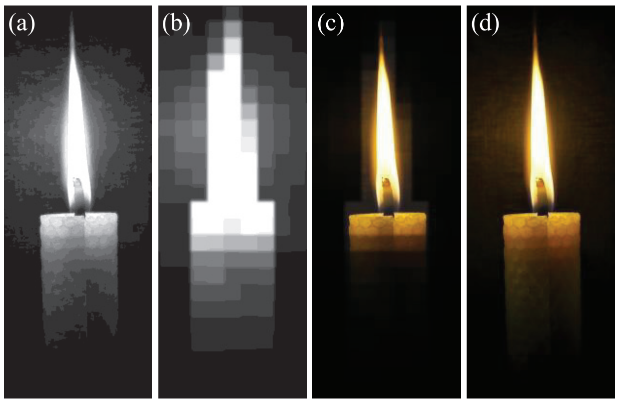

Fig. 1 The image rendering procedure of the high dynamic range LCD with a mini-LED backlight. (a) The maximum light image with each pixel the maximum value of RGB channels; (b) mini-LED lighting image according to the maximum light image and the local dimming unit allocation strategy; (c) mini-LED backlight through the original LC panel modulation; (d) mini-LED backlight through pixel compensated LC panel.

The simulation procedure is firstly creating the light image with each pixel the maximum value of RGB channels (Fig. 1a); and then calculating mini-LED lighting image according to the maximum light image and the local dimming zone allocation strategy (Fig. 1b). The pitch size of simulated square-shaped mini-LED is p=1mm. To investigate the effect of local dimming unit size on the visibility of halo effect, the local dimming unit can be 1×1, 2×2, 5×5, 10×10, 20×20, 40×40 mini-LEDs. With 3.2 times display height viewing distance of an 27 *inches* display, the viewing angles of the above local dimming unites are 0.10°, 0.20°, 0.50° , 1.0°, 2.0° and 4.0° respectively. If the light of mini-LED backlight going through the original LC modulation, there will be obvious block artifact (see Fig. 1c). To compensate the artifact, the modulation of LC should be reprocessed to make the light output as close as possible to the ideal image (see Fig. 1d for the final pixel-compensated image). As the existence of LC leakage, the halo effect exists. The LC CR corresponding to the leakage also affects the visibility of the halo effect. The LC CR used in the simulation are within the range of normal LC CR, with five levels which are 1000:1, 2000:1, 3000:1, 4000:1 and 5000:1.

2.2. Simulation results

Six types of local dimming unit size and five levels of LC CR are used in the final model for the artifacts simulation. Fig. 2 used the candle image to illustrate the perceptual effect. Comparing Fig. 2a and the rest of Fig. 2, the LCD with a mini-LED backlight really improves the contrast ratio of the whole image. In other words, the dynamic range increases. Due to the applied "maximum" algorithm, the dark area around bright area shows obvious light leakage effect which is the halo effect. Figures 2b, 2c and 2d are with local dimming unit 10×10, 5×5 and 1×1 mini-LEDs respectively. The size of one local dimming unit affects the visibility of halo effect significantly with the first glance.

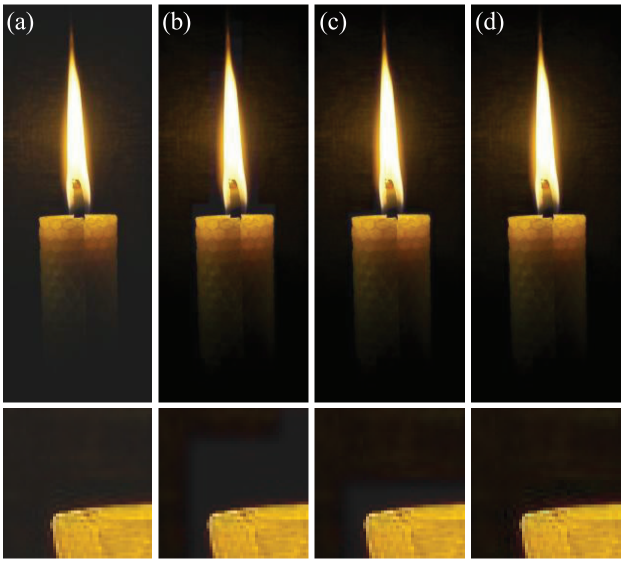

Fig. 2 Simulation of the perceptual results. (a) Low dynamic range image on the normal LCD without mini-LED backlight; (b) HDR image on the LCD with a mini-LED backlight, local dimming unit size 10×10 mini-LEDs; (c) HDR image on the LCD with a mini-LED backlight, local dimming unit size 5×5 mini-LEDs; (d) HDR image on the LCD with a mini-LED backlight, local dimming unit size 1×1 mini-LED.

3. Perception Experiments setup

3.1. Block visibility level scoring

To evaluate the halo effect of the display system, the block visibility level scoring experiment was designed to score the visibility level of one local dimming unit directly. The test stimuli are the extreme halo effect conditions, which are bright light leakage square on the totally dark background square. The experimental settings are shown in Fig. 3. The viewing angle of the background outer square is 10°. The inner square has six viewing angle choices and five LC CR levels. There are 30 stimuli for this scoring test. The five-grade impairment scale[6] was used to score the visibility level of the inner square. A score of 5 means the inner square is imperceptible, while a score of 1 indicates that a very annoying square is visible.

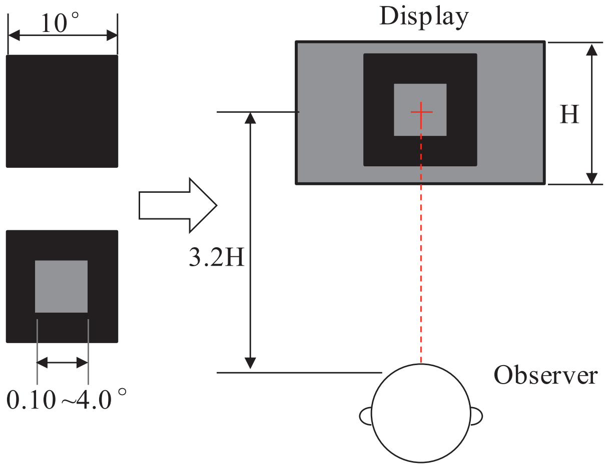

Fig. 3 Experimental settings, with at the left the background outer square (top) and the leakage inner square (bottom). The picture on the right hand side shows the appearance of the stimulus on the display. The distance between the observer and the display was 3.2H (3.2 times the display height).

One 27 *inches* OLED display was used for the simulated image rendering. The observers were seated at 3.2 times the display height away. The experiments were conducted in an otherwise dark room. Experiments were controlled by MATLAB script under Psychophysics Toolbox (Version 3), and the 30 stimuli for each participant were randomly presented.

3.2. Threshold test of the real scene

The halo effect visibility threshold test should consider the application on natural image because interesting parts of the natural image may divert the observers' attention from the halo effect. With the same viewing angles and CR combination, totally 30 simulated images were used in this experiment.

A two-alternative forced choice method was used, and observer needs to chose the preferred image (the one without halo effect) between the simulated and original images. The images were presented side by side with random order (Fig. 4). To avoid the effect of display angular brightness uniformity, the image presenting on the right side is a mirror image of the original one (left and right reversed).

3.3. Participants

A total of 23 subjects, including 10 women, participated in both experiments. The ages of subjects are ranging between 19 and 46 years and an average age of 23 years. All participants were tested to have normal (corrected to) visual acuity (1.0 on a Landolt chart).

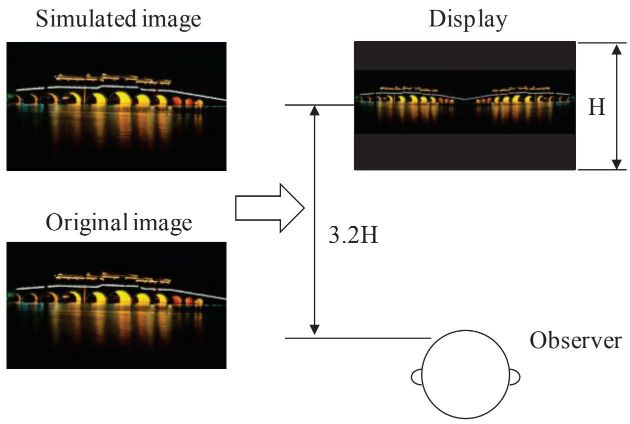

Fig. 4 Experimental settings, with at the left the simulated image (top) and the original image (bottom). The images were displayed side by side with random order. The image presenting on the right side is left and right reversed.

4. Result analysis

The score results of block visibility experiment were analyzed with SPSS software (IBM SPSS statistics 22.0). The results of an analysis of variance (ANOVA) is illustrated in Table 1, with "viewing angle (VA)" and "contrast ratio (CR)" as the fixed factors and "perceptual score" as the dependent variable. It is shown that both factors and their combination have high significant effect on the visibility of the halo effect ($p<0.01$).

The mean scores with 95% confidence interval are illustrated in Fig. 5. When the viewing angle is equal to or less than 0.2°, the scores are around or more than 4.0 (indicates perceptible, but not annoying); while the viewing angle is 0.5°, the scores are in between 3.0 (indicates slightly annoying) and 4.0; when the viewing angle is equal to or more than 1.0°, the scores are less than 3.0.

Table 1 The results of ANOVA analysis, investigating the effect of factors "viewing angle (VA)" and "contrast ratio (CR)" on the visibility of the halo effect.

Factor	Visibility of the halo effect		
	df	*F*	*Sig.*
VA	5	1251.649	0.000
CR	4	110.666	0.000
VA×CR	20	8.288	0.000

The threshold test experiment data were analyzed according to the binomial distribution. If the chance of the right option is p, the possibility of k times right choices within all n times choices is P as calculated with equation 1.

$$P = C(n,k) \times p^k \times (1-p)^{n-k} \quad (1)$$

where C is the number of combinations. In this experiment, p is equal to 0.5 when just guess and n is 23. The probability is less than 5% when the right choice is more than 16 within 23 times. With this method, stimuli with viewing angle equals to or more than 1.0° can be distinguished from the original image with perceptible halo effect. The factor "LC CR" has not present significant influence on this halo effect visibility threshold test.

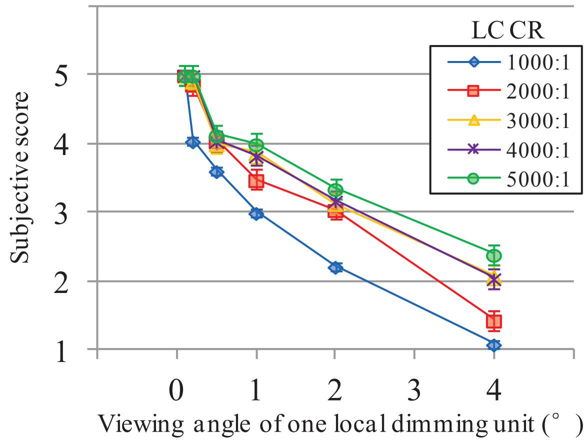

Fig. 5 Experimental results, with mean scores and standard deviations for each viewing angle of one local dimming unit under each contrast ratio of the liquid crystal panel.

5. Conclusion

To evaluate the perceptual artifacts on LCDs with a mini-LED backlight, perceptual experiments were designed to investigate the affecting factors and threshold values. Both "viewing angle" of one local dimming unit and "contrast ratio" of LC panel and their combination have high significant effect on the visibility level of halo effect. In the perceptual threshold test, halo effect of "viewing angle" equals to or more than 1.0° can be easily detected, while the "contrast ratio" has weak effect on threshold value.

6. References

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