New Brightness Uniformity Tuning Algorithm for LCD Panel with Local Dimming Function

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Abstract

LCD panels with 2D LED backlights often face brightness uniformity issues. This paper introduces an algorithm leveraging LED diffusion characteristics to address this. By projecting patterns and capturing luminance distributions, the algorithm corrects local brightness variations, compensating for mura effects and LED inconsistencies. Experimental results show significant improvements in 2D brightness uniformity, enhancing visual quality in demanding applications.

Author Keywords

Brightness Uniformity; demura; local dimming; 2D backlight LCD panels.

1. Introduction

The demand for high-quality visual displays has surged with advancements in modern technology, spanning applications from consumer electronics to automotive and industrial displays. Among display technologies, liquid crystal displays (LCDs) have remained a dominant solution due to their cost-effectiveness, long lifespan, and energy efficiency compared to organic light-emitting diode (OLED) panels [1][2]. The local dimming function is a pivotal technology for enhancing the dynamic contrast of LCD panels. By individually controlling the LEDs in a 2D backlight system based on input image data, local dimming achieves high dynamic contrast and low power consumption. However, the image quality of an LCD panel with local dimming is significantly influenced by the characteristics of the backlight system's light sources. A major challenge in these systems is the potential deterioration of brightness uniformity due to variations in the optical characteristics of individual light sources [3-5].

Techniques like optimizing lens arrays and diffusers have been widely studied to address this issue [6][7]. Simulation-based approaches, such as ray-tracing models, have also been employed to predict and mitigate brightness non-uniformity by refining the placement and intensity distribution of individual LEDs [8][9]. Despite these advancements, there are visible artifacts such as halo effects and luminance gradients, especially in applications requiring high dynamic range (HDR) and local dimming [10][11]. To address this mura issue in LCD panels with 2D backlighting, we have developed SmartBridge IC(SB7900) for automotive LCD panel which has our original local dimming circuit with brightness uniformity correction function as shown in Figure 1.

Our SB7900 with local dimming function can realize low power consumption and high dynamic contrast by individually controlling each LED brightness level and compensating display data based on the input image data. As depicted in Figure 1, the image data analysis module processes image data to identify necessary adjustments in brightness and contrast for each LED zone. This analyzed data is subsequently transmitted to the image processing module, where the gamma function for each brightness zone is interpolated to achieve a smooth curve. Concurrently, the analyzed image data is forwarded to the backlight control module, which regulates the brightness of each zone based on the corresponding brightness value. The output from this module is then input to the uniformity compensation module, where default base values for each LED are stored and can be configured as default settings. This module enables the adjustment of individual LED brightness to achieve optimal brightness uniformity.

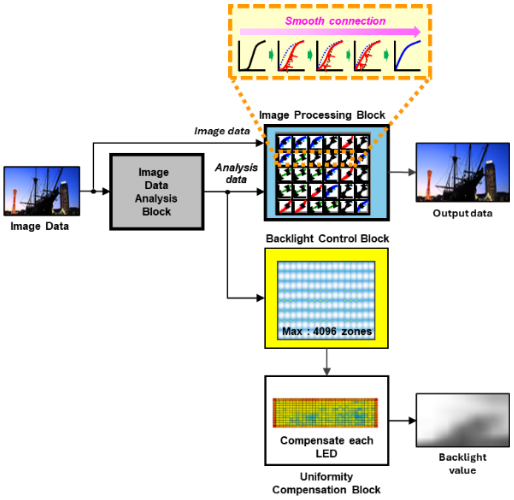

Figure 1. SmartBridge IC(SB7900) with local dimming function.

This paper details our methodology for achieving uniform brightness in 2D backlit LCD panels with local dimming and shows the improvement effect brightness of brightness uniformity on actual LCD panel operated SB7900. Our approach involves a comprehensive evaluation of individual LED brightness and their spatial contributions, utilizing a sequence of specifically designed test patterns projected onto the display. This technique not only compensates for manufacturing variances but also enhances the applicability of our solution to high-performance displays in automotive and VR applications, where stringent image quality standards are imperative.

2. Method

2.1 Local dimming with brightness compensation

To understand the proposed method for achieving brightness uniformity, it is first important to examine the limitations of the conventional demura approach. In the traditional technique, all LEDs in the 2D backlit array are simultaneously turned on, and their luminance data is captured using a 2D color analyzer. The data, which maps the positional brightness of each LED, is used to generate demura correction values. However, due to the diffusion characteristics of LEDs, this method often results in luminance artifacts, such as brighter regions around the corrected LEDs. These artifacts arise because light emitted by an LED spread across neighboring areas, interfering with the intended corrections and compromising overall brightness uniformity as shown in Figure 2(a).

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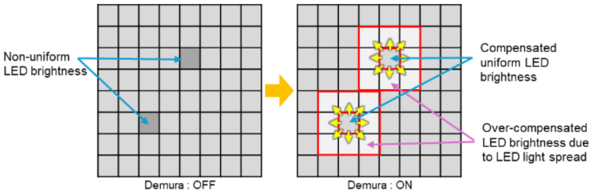
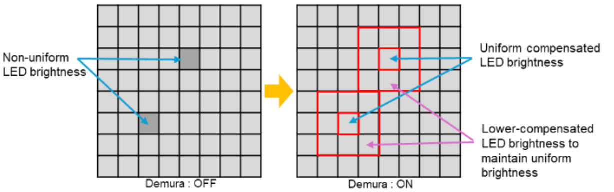


(a) Conventional Demura method



(b) Synaptics Demura method

Figure 2. Display panel with brightness uniformity compensation.

The proposed method addresses these limitations by employing a sequence of four carefully designed projection patterns instead of a single uniform illumination. These patterns are carefully structured to activate controlled regions of the LED array, enabling a more precise analysis of each LED's brightness and spatial influence. The patterns allow for the isolation of individual LED characteristics by minimizing the impact of surrounding LEDs during the measurement process as shown in Figure 2(b). Using a 2D color analyzer, the luminance data for each pattern is captured and analyzed through computational models to calculate the LED-specific compensation values.

This refined approach ensures that the demura correction accounts for the interactions between LEDs and their surroundings. By adjusting the brightness of not only the compensated LED but also its neighboring LEDs, the method achieves a uniform distribution of brightness across the entire panel. As a result, the final demura ON data effectively eliminates the uneven luminance observed in the conventional method, leading to superior brightness uniformity.

2.2 LED light spread Characteristics

To optimize 2D backlight systems, a detailed characterization of LED light diffusion is crucial. By illuminating specific test patterns, as shown in Figure 2, the angular light distribution of each LED is measured and modeled using a Cauchy distribution function as expressed in Equation 1.

$$f(x:x_0,\gamma)=\frac{1}{\left[\pi\gamma\left(1+\left((x-x_0)/\gamma\right)^2\right)\right]} \qquad (1)$$

In this function, x represents the random variable, x_0 is known as the location parameter and it indicates the peak or the center of the distribution and γ is the scale parameter, which determines the width of the distribution. A Cauchy distribution fitting procedure is employed to estimate the parameters that best describe the light diffusion characteristics of each LED. Referring to Figure 3, the total brightness level of a zone corresponding to a specific LED, termed the center LED, is recognized as the cumulative result of the light outputs from both the center LED and its surrounding LEDs. The center LED contributes approximately 30% of the total brightness, while the surrounding LEDs account for the remaining 70%.

Based on the estimated Cauchy distribution, a directivity filter is created to calculate the necessary brightness compensation for each LED, ensuring uniform illumination across the display. This filter represents the respective contributions of the center LED and the surrounding LEDs to the total brightness level of the zone of interest. The directivity filter includes directivity coefficients assigned to each LED. An example of this filter is shown in Figure 3 as a 3x3 matrix.

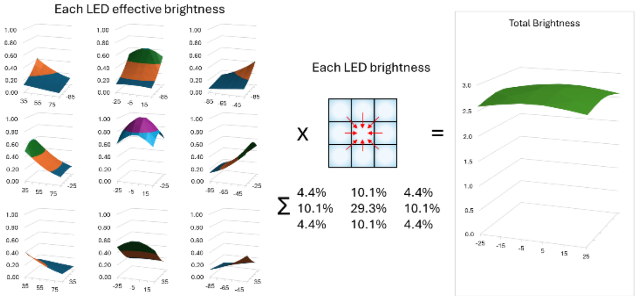


Figure 3. Effect of surrounding LEDs on total brightness of a LED.

2.3 Tuning brightness uniformity

After determining the LED diffusion characteristics, the tuning process also involves creating a brightness map for the light sources. This brightness map represents the brightness levels of each light source across the entire array. The demura coefficient factors are then calculated based on this brightness map. However, one challenge is that the light diffusion characteristics of each light source, as discussed in relation to Figure 3, can influence the measurement results due to the impact of surrounding light sources. To accurately measure the brightness levels of individual light sources, four specific test patterns shown in Figure 4 are used to illuminate the display panel.

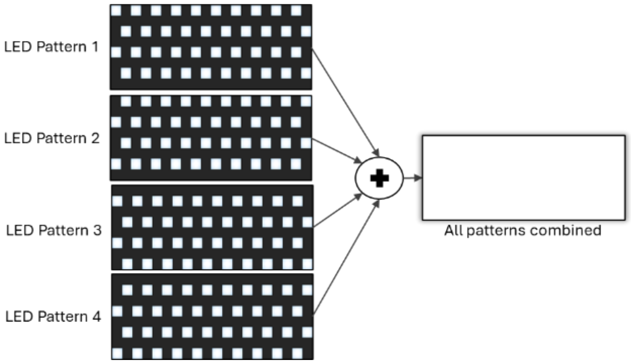


Figure 4. LED Tuning pattern.

The four patterns used in this study are designed to comprehensively cover all the LEDs in the 2D backlit system of the display panel. These patterns are generated based on the specific dimensions of the LED array in the display panel, allowing for systematic illumination and analysis. When all four patterns are combined, they illuminate the entire panel uniformly, providing a complete dataset for evaluating the LED characteristics. Each pattern selectively targets specific subsets of LEDs, enabling precise identification of their diffusion properties and localized brightness behavior. This strategic design ensures that data from the captured images can be effectively used to compute adjustments needed for uniform luminance across the display. Figure 5 shows example images captured using the four test patterns 1,2,3 and 4.

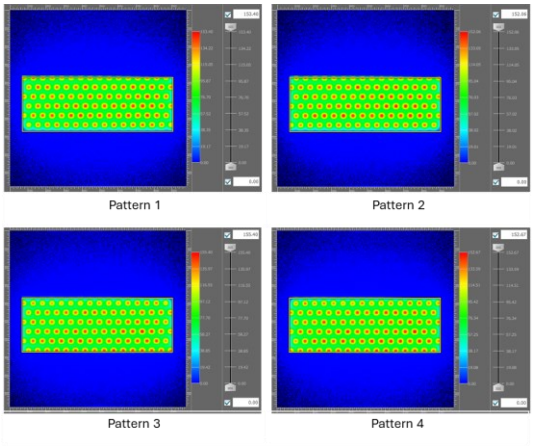


Figure 5. Measurement result.

Figure 6 demonstrates an example procedure for generating demura compensation factors for brightness uniformity. This process involves verifying the accuracy of the cumulative brightness map, depicted on the left side of Figure 6. Specifically, a simulated brightness mura map is created by applying the directivity filter to the combined brightness map of 4 test patterns. This simulated brightness mura map represents the brightness non-uniformity on the display panel when all light sources are on without the demura compensation.

The simulated brightness mura map is then compared to an “all LED-ON brightness map”, which is generated from an image captured while the display panel is fully illuminated. If the simulated brightness mura map closely matches the “all LED-ON brightness map”, it confirms the successful generation of the combined brightness map. However, if there is a significant discrepancy between the two-brightness map, the cumulative brightness map is discarded. The process of acquiring brightness maps for the four test patterns is repeated to generate a new cumulative brightness map.

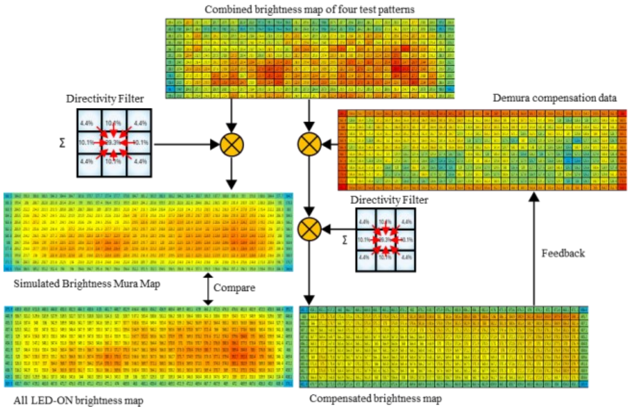


Figure 6. Brightness uniformity parameter generation flow.

The right side of Figure 6 describes the method for generating demura compensation data using the combined brightness map. The demura compensation data are determined through a recursive process. Initially, a set of demura compensation data is established, and a compensated brightness map is calculated by applying these initial factors and the directivity filter to the combined brightness map. Figure 6 illustrates an example method for calculating the compensated brightness map using the following expression:

$$\mathrm{BC_{image}(x,y)} = \sum_{\mathrm{m}}\sum_{\mathrm{n}} \begin{matrix}\mathrm{C_{image}(x-m,y-n)} \times \\ \mathrm{C_d(x-m,y-n)} \times \mathrm{D_c(m,n)}\end{matrix} \tag{2}$$

Here, (x, y) represents the 2D-LED array source in the x-th row and y-th column. $\mathrm{BC_{image}}$(x, y) is the measured brightness level of the LED at (x, y) in the compensated brightness map. $\mathrm{C_{image}}$(x-m, y-n) is the brightness of the LED at (x-m, y-n) in the combined brightness map. Cd (x-m, y-n) is the demura compensation factor for the LED at (x-m,y-n), and Dc(m,n) is the directivity coefficient of the m-th row and n-th column of the directivity filter

The demura compensation data is calculated to achieve a target brightness which is chosen as the center LED brightness of the panel. The differences between a target brightness level and the brightness levels of the respective light sources in the compensated brightness map are calculated. Based on these differences, the initial demura compensation factors are adjusted to generate a new set of demura compensation factors. A new compensated brightness map is then calculated using these updated factors. This process is repeated until the ratio of the maximum brightness level to the minimum brightness level in the compensated brightness map approaches one. In one implementation, the recursive process continues until this ratio falls within a range of 1.0-α to 1.0+α, where α is a small positive number. The final demura compensation data is stored in the LED coefficient RAM and used as demura data to implement the demura function by the display processor.

3. Results

To evaluate the performance of the brightness compensation algorithm, a 32x12 2D-backlit LED panel was utilized. The panel was driven by a Synaptics SmartBridge display processor with local dimming capabilities to assess the algorithm's effectiveness. We measured panel luminance using a Konica Minolta CA-2500 color analyzer. Figure 5 presents data captured using a 2D color analyzer for patterns 1, 2, 3, and 4. LED brightness values were extracted from their respective positions. Demura data, which corrects for non-uniformities in the display, was calculated at 600 nits. This data was then applied at three different brightness levels: 100 nits, 600 nits, and 1000 nits. Using measurements from Figure 5, a brightness map was generated by summing data from all four patterns. Tables 1 display the measurement results from the demura data calculated using Equation 1.

The evaluation metrics for brightness uniformity include non-uniformity and peak signal-to-noise ratio (PSNR). Non-uniformity is calculated using Equation 3, while PSNR is calculated using Equation 5. Here, L_{min} and L_{max} represent the minimum and maximum brightness, T is the target brightness, Lij is the brightness at position (i, j) in the LED array, m is the position of the LED in the row, n is the position of the LED in the column, and MSE is the mean square error as expressed in Equation 4.

$$\mathrm{Non-Uniformity} = \left(1 - \frac{L_{\mathrm{min}}}{L_{\mathrm{max}}}\right) \times 100 \tag{3}$$

$$MSE = \frac{\sum_{i=0}^{m}\sum_{j=n}^{n}\left(1 - \frac{L_{ij}}{T}\right)^2}{m \,\mathrm{x}\, n} \tag{4}$$

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{1}{MSE}\right) \tag{5}$$

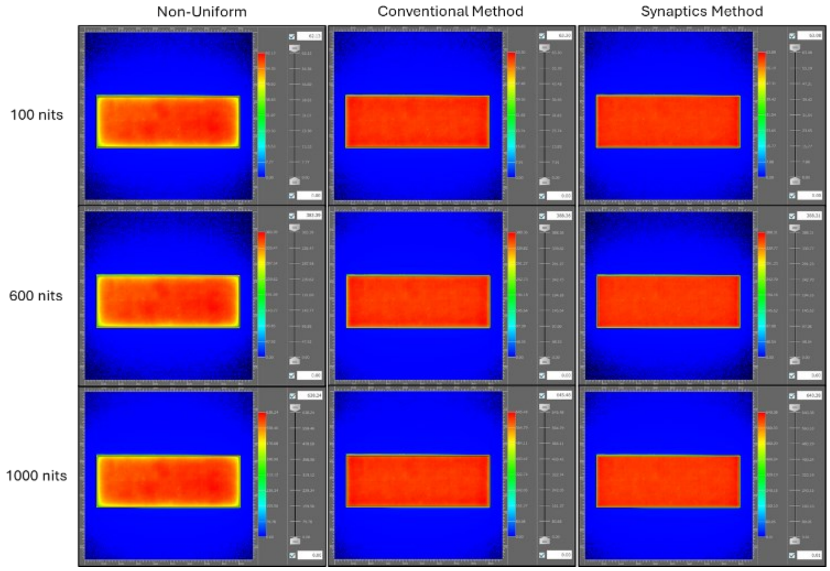


Figure 7. Brightness uniformity measurement result as observed using 2D color analyzer.

Figure 7 provides a visual comparison of brightness uniformity captured by the 2D color analyzer, showing results with the brightness uniformity function turned OFF and ON. It is evident that the brightness uniformity has significantly improved using the discussed algorithm.

Table 1. Panel measurement result.

Panel Brightness	Evaluation metric	Demura OFF	Conventional Demura	Synaptics Demura
100 nits	Non-Uniformity	41.77	14.1	5.52
	PSNR	19.67	31.09	39.47
600 nits	Non-Uniformity	40.89	14.14	5.66
	PSNR	19.66	30.85	39.17
1000 nits	Non-Uniformity	40.88	14.06	5.53
	PSNR	19.69	30.94	39.27

4. Conclusion

Accurate LED modeling is crucial for precise demura data calculation, essential for optimal display performance. Our innovative algorithm significantly improves brightness uniformity by tailoring individual LED light output. By employing four patterns, we accelerate the process of achieving uniform brightness. Experimental results validate the algorithm's effectiveness, demonstrating substantial improvements in 2D brightness uniformity. This advancement offers a promising solution for enhancing visual quality in demanding display applications, overcoming manufacturing limitations.

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