

Addressing Image Retention for MLED LTPS COG: A Compensation Method Based on Thermal Diffusion, Boundary Search, and Frame History

Zheyuan Song, Feng Hou, Shuguo Zhang, Ran Duan, Jingtao Xu, Yanhong Wu, Guannan Chen, Darun Tang, Xingqun Jiang
BOE Technology Group Co., Ltd, Beijing, China

Abstract

MLED technology enhances display performance with superior light output, contrast levels, and color rendering accuracy. However, MLED LTPS chip-on-glass (COG) must address image retention, resulting from decreased brightness in the LED red channel due to high temperature. This paper presents a compensation method, incorporating thermal diffusion, boundary search, and frame history. The approach is implemented on FPGA and successfully integrated into mass-produced MLED displays.

Author Keywords

Compensation method; Image retention; Image sticking; MLED; Boundary Search; Thermal diffusion filtering; Frame History

1. Introduction

The image retention of MLED is essentially caused by temperature difference, which will seriously affect the user experience. MLED is a promising and efficient LCD screen backlight technology that enhances image quality and contrast by placing large numbers of smaller LEDs behind LCD pixels. While this breakthrough technology has the potential to revolutionize displays, it also faces challenges. MLED LTPS COG operates at microampere current, and prolonged high-brightness display leads to heat generation in red pixel LEDs, reducing their efficiency and causing varying screen temperatures. This temperature difference results in image retention.



Figure 1. Brightness Variations Impact Regional Temperature Differences

This presents a notable obstacle, as image retention is likely to manifest in various scenarios, including static background images during presentations in meeting rooms, large screen displays at airports or train stations, and even in video games on certain smartphone apps. To address these challenges, this paper introduces a compensation algorithm based on thermal diffusion, boundary search, and frame history. This algorithm mitigates image retention in MLED displays by taking into account temporal and spatial dimensions. Deploying this methodology on a field programmable gate array (FPGA) proved that it can effectively enhance image consistency in MLED displays and support the mass production of MLED COG products.

2. Literature Review

Image persistence, a prevalent issue in display technologies such as OLED and its counterparts, has garnered considerable research and innovative efforts. Within the OLED domain, there has been a concerted focus by researchers and industry professionals on tackling the challenges associated with image retention.

To combat this, strategies for OLED displays have been proposed, which include modulating the voltage in accordance with the decay characteristics of OLEDs to sustain uniform luminance levels. Additionally, external compensation techniques have been implemented, leveraging Analog-to-Digital Converters (ADCs) within the column driver Integrated Circuits (ICs) to ensure even pixel illumination.[1]

However, when it comes to MLED displays, the task of managing image retention is further complicated by distinct technological hurdles. The current body of research and the compensation strategies in place have not yet provided a comprehensive solution to the particular difficulties encountered in MLED Chip-On-Glass (COG) configurations.[2] In response, this paper presents a groundbreaking compensation algorithm that integrates both temporal and spatial aspects to significantly reduce the impact of image retention, thus overcoming the existing technological barriers. This innovative methodology offers a resolution to an enduring problem within the field of display technology.

3. Methodology

This algorithm presents an innovative approach to mitigating image retention by employing grayscale coefficients, luminance contrast curves, and modeling spatial and temporal effects. It generates coefficient matrices and historical data to analyze the intricate relationship between luminance, chrominance, and temperature. This analysis is used to construct a lookup table (LUT) for grayscale compensation. Subsequently, compensation values for the current frame are computed based on screen content and historical data. The process involves boundary search and overlay. The historical data is continuously updated and weighted to enable real-time compensation, ultimately yielding the final compensated image.

3.1 Convert RGB Value to Gray

After inputting image data, the first step is to convert the RGB image into a grayscale image. By measuring the temperature rise of the red, green, and blue channels when displaying a full-screen image, the temperature rise ratio for the three channels (R:G:B) is obtained as a:b:c. This ratio is used as the scaling factor for converting the input RGB image into a grayscale image.

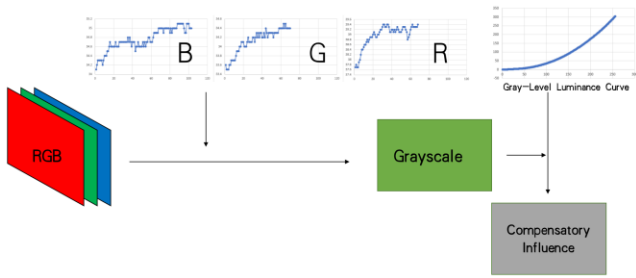


Figure 2. Grayscale to Compensatory Influence Value Transformation

Let the original RGB image be denoted as I_{RGB} , and the calculation formula for the R, G, B scaling coefficients is as follows:

$$I_{Gray} = a \times I_R + b \times I_G + c \times I_B \quad (1)$$

Because MLED screen's brightness under a pure white image corresponds one-to-one with grayscale values, compensating for grayscale values can enhance the overall uniformity of the screen's brightness and darkness. The compensation value Y is related to the grayscale G and can be fitted using the following formula:

$$Y = G^b \quad (2)$$

The power operation here can be replaced by a lookup table. All values in the input grayscale image are mapped through a lookup table to obtain the compensation image. Additionally, after converting RGB to grayscale values, the grayscale data within a unit screen area can be reduced in size by using a division operation to calculate the grayscale mean. This reduction is aimed at preserving basic patterns within the unit screen during subsequent compensation value calculations, while also reducing storage and computational requirements.

3.2 Boundary Search

Performing the mentioned operations yields the necessary data for subsequent processing. We introduce a boundary search algorithm to identify low grayscale regions within the compensation image.

The region is divided into n parts, and then we start searching for grayscale regions from the initial position at the outermost position of the compensation image and move inward sequentially. When the first high grayscale region is encountered during a search, the current search is completed. Subsequently, we assign values to the discovered regions in reverse order using a LUT. After assigning values, we move back to the initial position and continue the search until all boundary regions have been traversed.

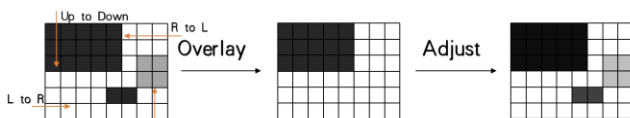


Figure 3. Boundary Search Method

The variation in search direction falls into four categories: top to bottom, bottom to top, left to right, and right to left. Each direction's search results in a boundary search image. These images from the four directions are combined to create the final boundary search image. Finally, the boundary search image overlays and adjusts with the previous compensation image to obtain the compensation image influenced by the boundary overlay. The relationship is expressed as follows:

$$C = A + B_{max} - B \quad (3)$$

where B_{max} denotes the maximum value within the set 'B,' 'A' is representative of the compensation image, and 'B' represents the combined result of overlaying boundary search images derived from four distinct directions. For clarity, we refer to the compensation image affected by this boundary overlay as 'C.'

3.3 Frame History

After obtaining the boundary search compensation image, temporal factors are incorporated into the equation. To estimate pixel compensation values for the current frame, historical data from the past thirty minutes, comprising 1800 frames, is stored in a historical frame sequence cache pool. Each frame of historical data represents compensation image information affected by boundary overlay.

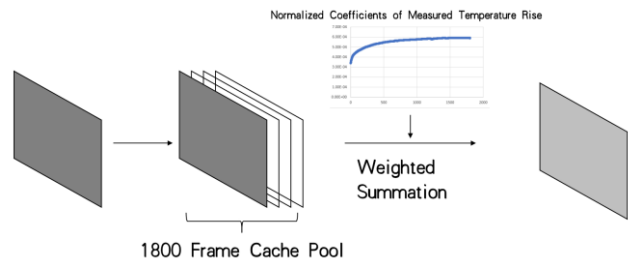


Figure 4. Normalization and Weighted aggregation of historical frame data

When evaluating the impact of historical data, weighted aggregation is applied to the 1800 frames of image data. The temporal window weight is represented as a 1×1800 normalized vector, with each value corresponding to the weight assigned to individual historical frames during aggregation. All frames in the cache pool are then multiplied by the temporal window weight vector, and the products are summed to generate a comprehensive historical impact image.

To address the tic-tac-toe phenomenon arising from varying temperatures in the aluminum frame and the inner part of the screen, we propose two sets of time frame weight coefficients.

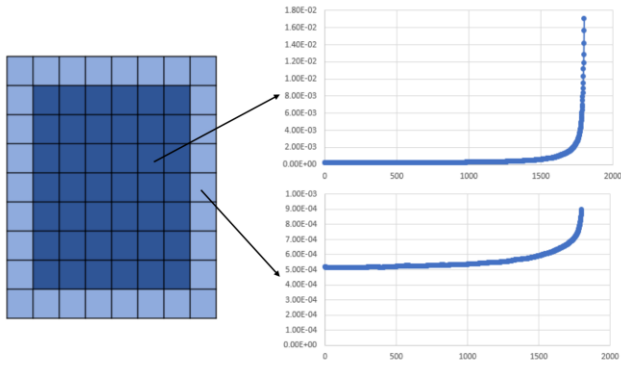


Figure 5. Normalization and Wrighted Aggregation of Historical Frame Data

3.4 Thermal Diffusion Filter

In addition to the temporal dimension, it is essential to consider spatial factors in the analysis. Due to variations in pixel values across different positions within a screen, the temperature distribution also varies. As a result, different locations within the screen have distinct compensation values. To describe the thermal diffusion phenomena within a screen, a 9x9 Gaussian filtering kernel is employed to filter the screen's content.

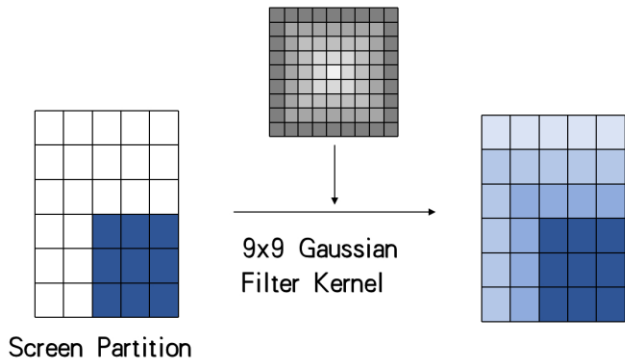


Figure 6. Screen Heat Diffusion

3.5 Compensation

Let the cross-screen 3x3 thermal diffusion compensation image be denoted as C_{9m9} , the individual screen thermal diffusion compensation image as C_T , the maximum compensation value image as C_{max} , and the compensation value image as C_{final} . Thus:

$$C_{final} = P_{1v} C_{max} \times [P_T \times C_T + (1 - P_T) \times C_{9m9}] \quad (4)$$

Where P_{1v} represents the maximum brightness coefficient, and P_T represents the thermal diffusion weight coefficient for an individual screen.

Once the compensation value image is obtained, the original RGB image can be compensated by subtracting the compensation value

image from it. For the three different channels, the compensation factors are also distinct. Let the original RGB image be I_{RGB} , and the RGB three-channel compensation factors be C_R , C_G , and C_B , respectively. The compensated values for the three channels are as follows:

$$I_{C_R} = I_R - C_R \times C_{final} \quad (5)$$

$$I_{C_G} = I_G - C_G \times C_{final} \quad (6)$$

$$I_{C_B} = I_B - C_B \times C_{final} \quad (7)$$

Ultimately, the amalgamation of the adjusted values across the three channels, represented as I_{C_R} , I_{C_G} , and I_{C_B} , constitutes the compensated frame that is outputted.

4. Implementation

The algorithm is implemented on an FPGA chip, comprising three primary components.

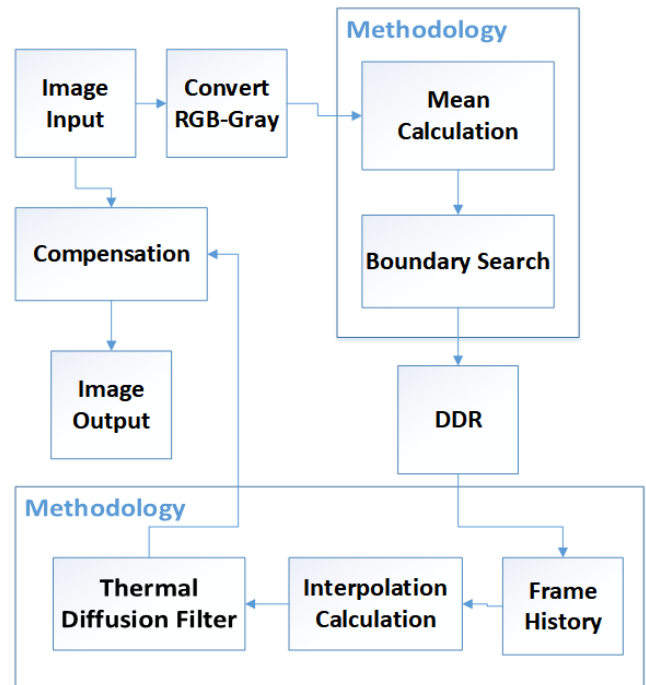


Figure 7. Implementation Structure in FPGA

The process begins with the initial stage of image data processing, where RGB values are transformed into grayscale equivalents. Concurrently, within the methodology framework, mean calculations are performed to assess average grayscale values across segmented regions. Subsequently, boundary search operations are executed to refine these values, followed by adjustments and normalization to ensure consistency.

The grayscale data is then forwarded to the second phase, which entails data processing through a Double Data Rate (DDR) memory interface. This stage is crucial for the efficient handling of the large datasets generated by the initial conversion process.

In the third and final stage, the system calculates the mean of 1800 frame weights, a process that is part of cross-clock domain processing. This involves complex operations such as interpolation calculation, which is informed by frame history data, and thermal diffusion filtering that accounts for both in-screen and inter-screen variations. The methodology also includes the modification of ROM coefficients to ascertain three distinct pixel compensation coefficients. These coefficients are then applied in image compensation operations, which integrate the three pixel compensation coefficients, the original pixel compensation values, and the RGB values to produce the final image output.

It is imperative to acknowledge the constraints of FPGA resources. To address this, the system employs innovative approaches to optimize the use of logic resources within the FPGA. Pipeline operations are utilized for data processing, which serves to minimize the demand for data storage. The strategic use of Look-Up Tables (LUTs) circumvents the need for multiplication and division operations, thereby substantially reducing the consumption of chip resources.

The integration of this algorithm into an FPGA paves the way for the large-scale manufacturing of MLED displays. This technology is particularly relevant in high-end markets, such as private home theaters and integrated display screens, where the demand for superior display performance is paramount.

5. Results and Discussion

The compensation IP's performance was evaluated subjectively and objectively.

Objective Testing: Using the CIE 1976 u'v' chromaticity diagram, we measure the (u', v') value of the center point of each display module, and get the average value of u and v and the value of delta uv, and finally find u' and v'. The maximum difference in values is ≤ 0.005 , which meets the test requirements.

Table 1. Test Results.

Before Compensation			After Compensation		
<i>u average</i>	<i>v average</i>	Δuv	<i>u average</i>	<i>v average</i>	Δuv
0.193877	0.4393903	0.00367	0.1894282	0.4395435	0.002322
0.194624	0.4397188	0.00401	0.1889485	0.4392431	0.003422
0.195547	0.4395324	0.00382	0.1893871	0.4388809	0.002677
0.199286	0.4397824	0.00729	0.1920731	0.4389498	0.002221

Subjective Testing: When evaluating the visual effects of the screen, it was observed that regardless of the style of images used for aging, temperature difference artifacts were eliminated, and any scene was displayed uniformly. Continuous illumination for 30 minutes did not result in any visible afterimages. Residual images caused by temperature and grayscale differences have been eradicated, ensuring consistent image quality and significantly enhancing the subjective visual experience.



Figure 8. Demonstration of Ultimate Compensation Results

6. Conclusion

This algorithm is compatible with sub-4K screens of varying sizes, providing intelligent image retention compensation through image processing, without additional hardware costs. Implementing this on FPGA has broad applicability in mass-producing MLED displays and extended display products, establishing it as an industry-leading innovation.

To encapsulate the findings, this research underscores the pivotal function of the compensation technique in tackling image retention issues in MLED COG panels. Looking ahead, studies should concentrate on enhancing image clarity, diminishing visual distortions, and boosting screen capabilities to spur advancements in the field of display technology.

7. Acknowledgements

I extend my sincere thanks to the BOE AI Algorithm and FPGA Hardware Technology teams. Your vital contributions, support, and expertise greatly influenced the success of this project.

8. References

- [1] Kwon, J., Lee, C., Chae, Y., & Murmann, B. (2020). Design Considerations for External Compensation Approaches to OLED Display Degradation. In 2020 IEEE International Symposium on Circuits and Systems (ISCAS) (pp. 1-4). IEEE.
- [2] Wu, Y., Zhang, S., Duan, R., Chen, G., Liu, Y., & Leng, C. (2023). Grid Pattern Image Sticking Compensation Method for MLED Splicing Screen. In International Conference on Display Technology 2023 (Volume 54, Issue S1) (pp. 28-31).
- [3] Kam, K., Yu, T., Behrman, K., Yu, C., & Kymissis, I. (2020). Characterizing Image Retention for HDR OLED Displays. SID DIGEST 2020, 51(1), i-lviii, 1-652, I-XV, 653-1311, I-XV, 1312-2125.
- [4] Park, H.-J., Lai, L., et al. (2003). Analysis of IPS Mura, Image Sticking, and Flicker caused by Internal DC Effects. In SID Digest, SID Symposium Digest of Technical Papers, 34(1).
- [5] Song, Z., Hou, F., Zhang, S., Wang, X., Duan, R., Wu, Y., Chen, G., Zhang, Z., Guo, R., & Jiang, X. (2024). Eliminating Tic-Tac-Toe Image Retention in MLED Displays through Temporal and Spatial Compensation Methods. Society for Information Display Transactions. <https://doi.org/10.1002/sdtp.16999>