Paper 21-2 has been designated as a Distinguished Paper at Display Week 2025. The full-length version of this paper appears in a Special Section of the *Journal of the Society for Information Display (JSID)* devoted to Display Week 2025 Distinguished Papers. This Special Section will be freely accessible until December 31, 2025 via:

https://sid.onlinelibrary.wiley.com/doi/full/10.1002/jsid.2079

Authors that wish to refer to this work are advised to cite the full-length version by referring to its DOI:

https://doi.org/10.1002/jsid.2079

A Color and Brightness Shift Compensation Method for OLED TDDI Panel Using Metal-Mesh Capacitive-Touch Sensor with Temperature Sensing

Wan-Nung Tsung, Xuan-Yong Lin, Hua-Wei Liu, Shang-Yu Su, Chen-Yu Lin, Feng-Ting Pai, Chih-Chang Lai, Ching-Chun Lin

Novatek Microelectronics Corporation, Hsinchu, Taiwan

Abstract

Color and luminance of OLED panel may shift under different ambient temperatures. To address this, raw data from touch sensors can be used to obtain local temperature information. By using this data, the proposed compensation method can be employed to solve the effects of temperature-induced color and luminance shifts. After compensation, OLED panels can provide a more stable and reliable visual experience in diverse ambient temperatures.

Author Keywords

AMOLED display, temperature, Metal mesh capacitive touch sensor, Touch panel, Uniformity, Color Calibration.

1. Introduction

In recent years, AMOLED displays have been widely used in various devices such as TVs, smartphones, and smartwatches. These panels may exhibit color and brightness shifts when used in diverse environments, such as cold or hot days. Basic examination of the phenomenon, we placed an OLED panel on a heat plate set to 25°C and 85°C as shown in Figure 1. The color bar represents brightness levels, with red indicating higher brightness and blue indicating lower brightness. By comparing both sides of Figure 1, it can be observed that the brightness of the panel at 80°C is lower than that of the panel at 25°C.

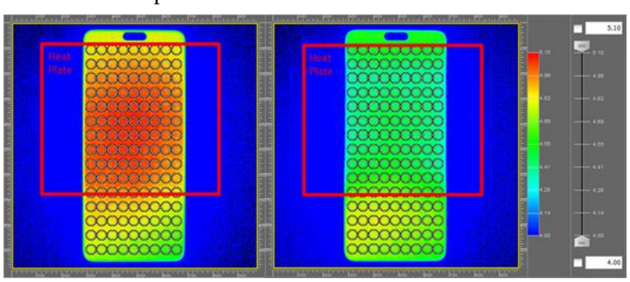

Figure 1. The brightness of OLED TDDI panel at 25℃ (left side) and 80℃ (right side).

To explore the causes of variations at high and low DBV and temperature, we reviewed relevant literature and hypothesized that temperature might affect the characteristics of the Thin-Film Transistor (TFT) in the AMOLED circuit and the recombination center in the OLED device [1-4]. Alternatively, under other conditions, this may be attributed to the inherent characteristics of the OLED device itself [5].

2. Experimental Environment

To investigate this phenomenon, we set up an experimental environment, as shown in Figure 2, consisting of a display panel, a heat plate, a thermal imaging camera (FLIR E6 Pro), and a colorimeter CA2500. The heat plate was used to heat the display panel locally, while a thermal imaging camera was used to monitor the temperature changes of the display panel. The colorimeter CA2500 was used to measure the changes in 2D colorimetry and luminance. Additionally, we developed an Auto-Measurement System that enabled automatic measurement of the data on high/low DBV (display brightness value) and grayscale at different temperatures.

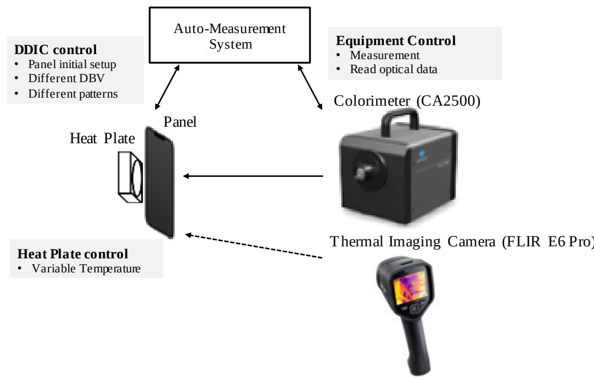

Figure 2. The system to Auto-measure the different patterns in different temperature.

3. Transform Cap. Values to Touch Raw Data

So far, we have observed that the brightness of the OLED panel can vary at different temperatures. There are also numerous related studies in this field [6-7]. To address this issue, we first need to find a way to detect the current temperature on the surface of the OLED panel. In traditional methods, the temperature sensor is typically positioned on one side of the panel, which means it can only sense the adjacent temperature and fails to represent the entire temperature distribution across the panel. The temperatures across the entire panel are usually not uniform. For example, the temperature near the IC tends to be higher than those at the far end of the panel, due to the heat generated by IC operation. In this paper, we propose using metal mesh capacitive touch sensors to measure temperature. Metal mesh capacitive touch sensor covers the entire display panel, enabling the detection of temperature variations in any region.

The structure of OLED TDDI panel is shown in Figure 3. TDDI can obtain touch raw data from metal mesh capacitive touch sensor through TP (Touch Panel) trace. The touch raw data obtained from metal mesh capacitive touch sensor represents the parasitic capacitance of metal mesh (1). In equation (1), C is presented as the parasitic capacitance of metal mesh, ε is presented as permittivity, A is presented as area of metal mesh, and d is presented as thick of insulation layer.

$$C = \varepsilon \frac{A}{d} \dots (1)$$

ISSN 0097-996X/25/5601-0262-$1.00 © 2025

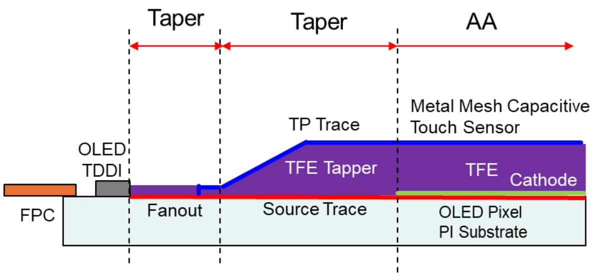

Figure 3. The structure of OLED TDDI panel.

4. Transform Touch Raw Data to Temperature

Within the concept of the transformation algorithm, once the delta of the raw data is obtained, which is positively correlated with temperature information, these data can be mapped to their corresponding temperatures. A lookup table or linear mapping functions can be used to achieve this. As shown in Figure 4, at least two linear mapping functions are required to transfer the delta of raw data into the temperature domain. One function is used for high temperatures, while the other is used for low temperatures. This is because the relationship between the delta of raw data and temperature is non-linear, and a single linear mapping function is not sufficient to accurately represent this relationship.

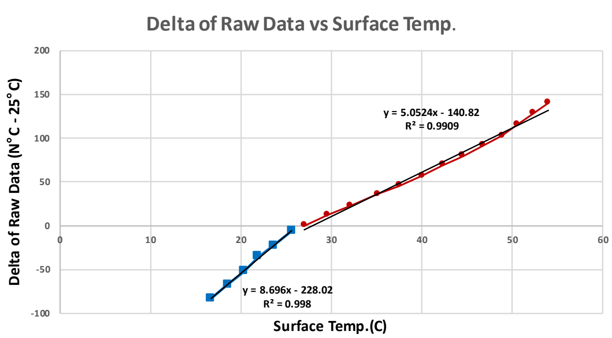

Figure 4. Relationship between processed delta of touch and surface temperature.

It must be noted that the variation in touch raw data due to temperature changes is an order of magnitude smaller than the actual touch values. In scenarios where actual touch is not considered, we can use the above LUT method for calculation. However, in practical applications, it is necessary to consider the impact of touch and the temperature of the finger after touching on the sensors. This is the direction we will continue to improve in the future.

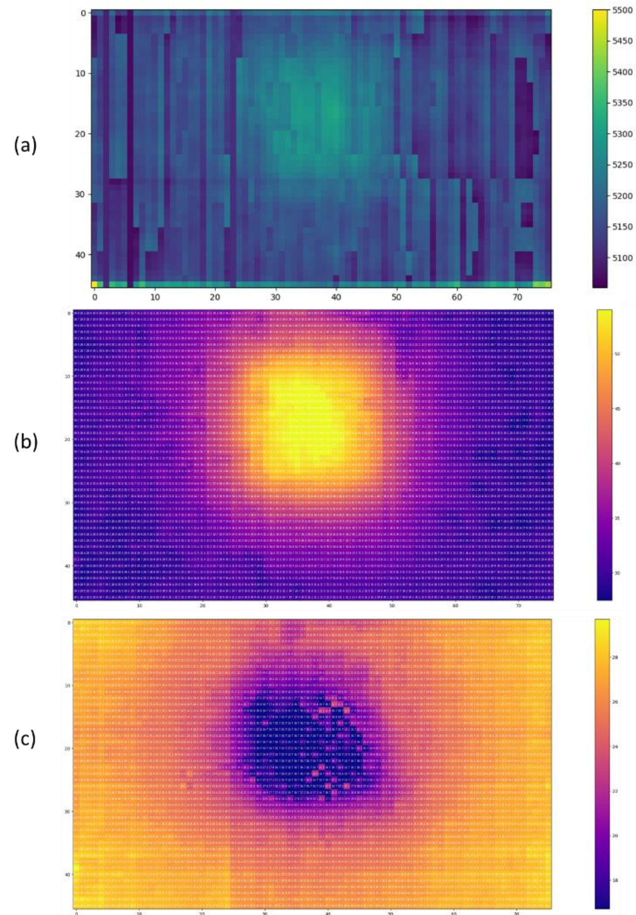

Figure 5. 2D heat maps of touch raw data, with x and y axes mapping to the physical position of the panel, displaying temperature variations across the panel's surface. (a) touch raw data at high temperature heat source (b) transformed temperature distribution of high temperature source (c) transformed temperature distribution of low temperature source.

Figure 5 shows the touch raw data and results of transformed absolute temperature. Figure 5(a) presents a 2D color map, where the x and y axes represent the corresponding positions of the touch sensor on the panel. The different colors represent the raw data values sensing by touch sensors. It appears unrelated to temperature, as raw data may be influenced by manufacturing defects. In contrast, through algorithmic processing, we can obtain Figure 5 (b)(c). The different colors represent the absolute temperature distribution. It clearly reveals the position of the heat source and how the heat expands, making it a more accurate representation of temperature changes.

To verify the accuracy of the transformed local temperature, we use a thermal imaging camera to compare the results. The temperature difference observed was less than ± 1.5 °C at high temperature and ±3°C at low temperature. This phenomenon may be attributed to variations in each touch sensor. Although there is still room for improvement in temperature precision, it is sufficient for our subsequent algorithms to perform further compensation.

5. Compensation Algorithms

To compensate the color and luminance shift caused by temperature of display, we must consider at least 4 conditions (pixel value, DBV, position, temperature). The line charts in Figure 6 display data related to different positions on a panel, arranged from the upper left to the lower right. The heat source is located at about 60th position. In Figure 6(a)(b), the y axis represents the luminance division of 25 degrees and *N* degrees, and in Figure 6(c)(d), the y axis depicts the color difference (delta uv) between 25 degrees and *N* degrees. $N \in 05,15,45,65,85$. The two figures, Figure 6 and Figure 7, illustrate how color and luminance vary under different DBV and gray level, separately.

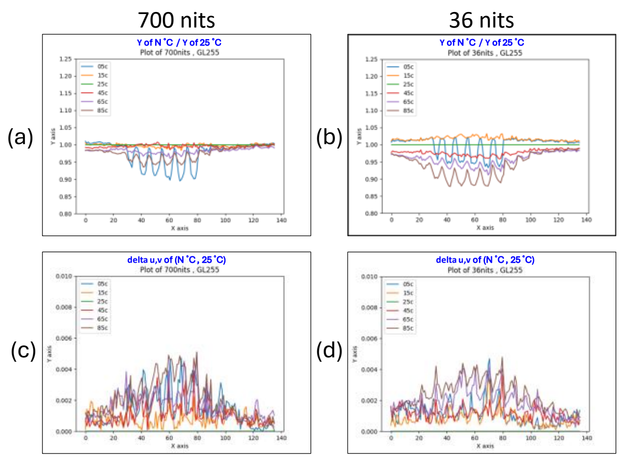

Figure 6. (a) (b) are the luminance shifts under different display brightness values. (a) is 700 nits, and (b) is 36nits. (c) (d) are the color shifts under different display brightness values. (c) is 700 nits, and (d) is 36nits. The heat source is located at about 60th position.

According to the observation, we proposed a thermal luminance and color compensator to deal with this phenomenon caused by temperature variation. Based on [8], we incorporate ambient temperature as a critical factor. The process begins with a touch sensor that captures ambient temperature, which is then converted into 2D temperature information, the temperature readings are mapped spatially to create a matrix representing temperatures across a surface. As shown in Figure 12, a compensation ratio is computed using this 2D temperature data, which takes into account panel operational conditions, display brightness values and gray levels to adjust for any discrepancies. The next step involves interpolating the calibration table to establish sub-pixel-based compensation ratios. Finally, the calculated compensation ratio is added to the original pixel values of the image, enhancing the visual representation by correcting temperature-related variations. This process allows color accuracy and consistency, ensuring that the AMOLED displays perform optimally in varying environmental conditions. Ultimately, the integration of ambient temperature into the compensation architecture enhances the overall visual quality for users.

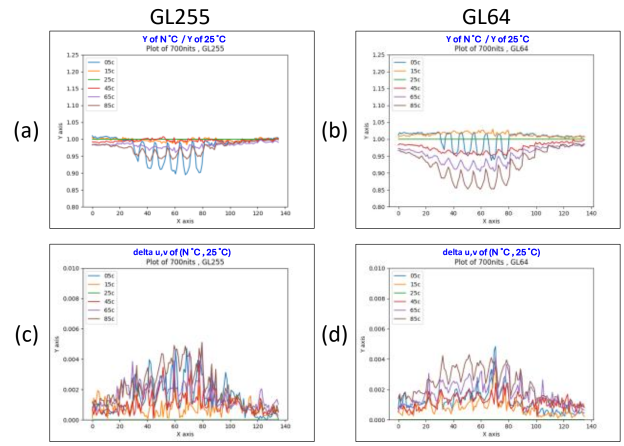

Figure 7. (a) (b) are the luminance shifts under different gray levels. (a) is GL255, and (b) is GL64. (c) (d) are the color shifts under different display brightness values. (c) is GL255, and (d) is GL64. The heat source is located at about 60th position.

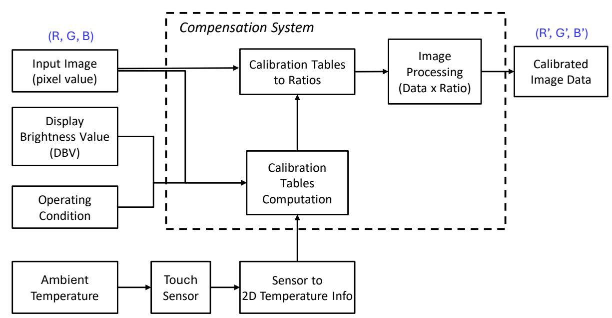

Figure 9. Proposed thermal luminance and color compensator.

The compensation ratios can be obtained by using a panel model. There are multiple methods to obtain a panel model, including machine learning techniques like CNN [9] or using a linear matrix, each offering different approaches to achieve accurate calibration and performance. Refer to [8], we are using a panel model represented by a 3x3 linear matrix to demonstrate the compensation results. As shown in (2), $[X_{Ri}, X_{Gi}, \dots, Z_{Gi}, Z_{Bi}]$ represents the panel model of specific area of the panel, $[X_T, Y_T, Z_T]$ represents the chrominance of the target area, and $[Ratio_{Ri}, Ratio_{Gi}, Ratio_{Bi}]$ represents the compensation ratios. The matrix values may vary depending on different factors, such as DBV, the gray level, the position of the panel, and the ambient temperature. These variations occur because the panel's behavior can change based on environmental and operational conditions.

Calibrated i^th area

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = \begin{bmatrix} X_{Ri} & X_{Gi} & X_{Bi} \\ Y_{Ri} & Y_{Gi} & Y_{Bi} \\ Z_{Ri} & Z_{Gi} & Z_{Bi} \end{bmatrix} \begin{bmatrix} R \times RatioRi \\ G \times RatioGi \\ B \times RatioBi \end{bmatrix} \quad (2)$$

6. Compensation Results

To accomplish compensation, we need to collect the optical data by measuring panels under different temperature conditions. The following results are based on our thermal compensator's performance. In each figure, the x-axis represents the gray level under varying temperatures, where temperature increases progressively along this axis. The y-axis in Figure 13 shows the luminance ratio between 25°C and temperature *N*°C. In this case, a ratio closer to 1 is preferable. In Figure 14, the y-axis displays the maximum color difference between 25°C and *N*°C, and a lower difference is more desirable for color stability. The blue bars in both figures illustrate the values after applying compensation, and the red bars are before applying compensation.

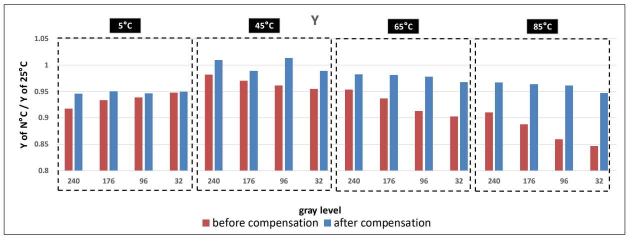

Figure 10. The luminance difference before and after compensation.

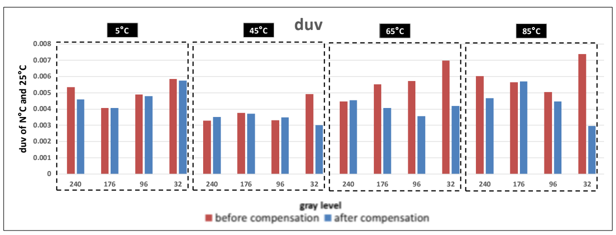

Figure 11. The color difference before and after compensation.

7. Conclusion

In this paper, we proposed a compensation architecture that successfully solves the color and luminance shift of OLED panels, which is caused by ambient temperatures, by using touch raw data from touch sensors to obtain absolute temperature information. We also provide a method to transfer touch raw data to temperature information, since touch raw data cannot be directly used, and instead, needs to be transferred into delta of touch raw data and then using look up tables or linear mapping functions to transfer to temperature information. To develop effective compensation architecture that can be used under different conditions, we observe the relationship between color difference and luminance difference under different display brightness values and gray levels, and take these factors as inputs of our compensation system. According to our experimental results, the proposed compensation architecture can ensure optimal performance across various environmental conditions.

8. References

1. Kanda, Kouichi & Nose, Kouichi & Kawaguchi, Hiroshi & Sakurai, Takayasu. (2001). Design impact of positive temperature dependence on drain current in sub-1-V CMOS VLSIs. Solid-State Circuits, IEEE Journal of. 36(10). 1559 - 1564. 10.1109/4.953485.
2. Rahmani, Mohsen & Xu, Lei & Miroshnichenko, Andrey & Komar, Andrei & Camacho Morales, Rocio & Chen, Haitao & Zárate, Yair & Kruk, Sergey & Zhang, Guoquan & Neshev, Dragomir & Kivshar, Yuri. (2017). Reversible Thermal Tuning of All-Dielectric Metasurfaces. Advanced Functional Materials. 27. 1700580. 10.1002/adfm.201700580.
3. B. S. Amrutur and M. A. Horowitz, "Fast low-power decoders for RAMs," in IEEE Journal of Solid-State Circuits, vol. 36, no. 10, pp. 1506-1515, Oct. 2001, doi: 10.1109/4.953479.
4. Osman, Ashraf A., et al. "Zero-temperature-coefficient biasing point of partially depleted SOI MOSFET's." *IEEE Transactions on Electron Devices* 42.9 (1995): 1709-1711.
5. Xi, Suping, et al. "P-13.6: The investigation on high-temperature color deviation of flexible AMOLED display." *SID Symposium Digest of Technical Papers*. Vol. 54. 2023.
6. Yun-Hung Shen, Steve Wiyi Yang; MStar Semiconductor Inc Taiwan, assignee. Temperature-dependent overdrive circuit for LCD panel and method of implementing the same [Internet]. United States patent US7821488B2. 2008 Sept 18 [cited 2029 Aug 25]. 11 p. Available from: https://patents.google.com/patent/US7821488B2/en
7. Su, Q., Hu, P., Chen, D., Qin, W., Shao, X., Li, P, Miao, Y., Tian, X., Yu, J., Lee, S., Liao, Y., Rui, H., Ma, Q., & Wang, Z. (2024). Dynamic Invocation of Liquid Crystal Overdrive Tables by Utilizing Temperature Sensor Integrated in the LCD Cell. The Society for Information Display, 55(1), 2068–2071.
8. TSUNG, Wan-Nung, et al. P-62: Adaptive Pixel-Based Local Color Uniformity Compensation for AMOLED Displays. In: *SID Symposium Digest of Technical Papers*. 2022. p. 1276-1279.
9. PAN, Tzu-Lung, et al. 58-1: A Novel On-line, Fast Color Correction by Machine Learnings. In: *SID Symposium Digest of Technical Papers*. 2024. p. 793-796.