Adaptive Optics De-Mura Technology for OLED Displays

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Abstract

This paper introduces the two main types of Mura currently existing in OLED displays: uneven display and vertical Mura, and their optical-electrical characteristics. Based on the existing implementation of optical De-Mura and the limitations of Mura compensation, a quantitative feature extraction model for these two types of Mura is established, and the result of feature recognition is used to adaptively select more suitable optical De-Mura photography, data processing, and compensation IP configuration, which effectively improves the compensation ability of optical De-Mura and production yield. With these approaches, this research will probably spread a significant reference value for optical De-Mura of OLED and other display technologies.

Author Keywords

OLED; Optical De-Mura; Adaptive Mura compensation

1. Introduction

OLED display has become a mainstream display technology due to its advantages of light and thin, high display quality, low power consumption and easy to achieve flexibility and shape. With the maturity of DBI (De-Burn in) compensation technology and its application in OLED displays, the "burn-in" problem has been effectively solved [1]. The development and iteration of a new generation of organic luminescent materials have significantly improved the luminous efficiency. The development and application of MLP(Micro Lens Panel) and CFOT(Color filter on TFE) technology have significantly improved the light taking efficiency of the device [2] [3]. With the development and application of SLOD (Stacked Layer OLED Device) technology, the current density of OLED devices is further significantly reduced, and the power consumption is also significantly reduced [4]. With the application of the above technologies, the life time problems of OLED displays have been well solved, and the power consumption of OLED displays can also be effectively reduced. However, with the reduction of the TFT current of the substrate used to drive OLED devices and the reduction of the current density of OLED devices, the Mura problem of OLED displays is becoming more and more prominent.

The common Mura of OLED display mainly includes Sandy Mura, vertical Mura, horizontal Mura, uneven display, black and white block, etc. The fundamental cause of the formation of these Mura is the fluctuation of Vth and SS process of LTPS TFT and the fluctuation of OLED device film thickness, which lead to the inconsistency of brightness or chroma in different regions. There are three commonly used Mura compensation methods: a. Driver circuit compensation. By using sub-pixel circuit design with compensation function, the Vth difference of driving TFT will be removed, which has been widely used in the existing small and medium-sized display product, but this technology takes up the charging time of sub-pixel, which leads to the insufficient compensation of Vth. On the other hand, this method cannot compensate the Mura caused by other process fluctuations; b. Optical De-Mura compensation. This technology can effectively compensate various Mura, and its compensation process is simple and low cost, which is widely used in OLED display, LCD, Micro LED and other display technologies; c. External current compensation. This technology requires high accuracy and stability of the acquisition circuit, and is still in the development stage [5].

The working principle of optical De-Mura is shown in Figure 1, which is presented in the following steps: First, the brightness of each sub-pixel under specific brightness and gray level of the display is collected by an industrial camera; then the optical-electrical curves of each sub-pixel are fitted with the brightness data of different gray level; and the next, the compensation values and compensation parameters are obtained according to the each sub-pixel optical-electrical curves and the target optical-electrical curves; finally, the compensation under all DBV and all gray levels can be obtained according to the De-Mura IP built into the Driver IC. The existing optical De-Mura usually performs Mura acquisition and compensation for each display. However, the Mura types and Mura degrees of each displays are different, so the best compensation effect cannot be achieved by using the same photo patterns, compensation parameters and IP configuration. In order to improve the compensation ability and yield, this paper introduced the adaptive optical De-Mura. Through the analysis and identification of the Mura characteristics, the type and degree of Mura are obtained, so as to select a more appropriate optical De-Mura scheme for compensation, which can improve the compensation ability of Mura. According to the yield data after existing optical De-Mura compensated, uneven display and vertical Mura are the main defects, while other Mura such as Sandy or horizontal Mura defect rate is very low. Therefore, this paper is focused on adaptive optical De-Mura based on uneven and vertical Mura.

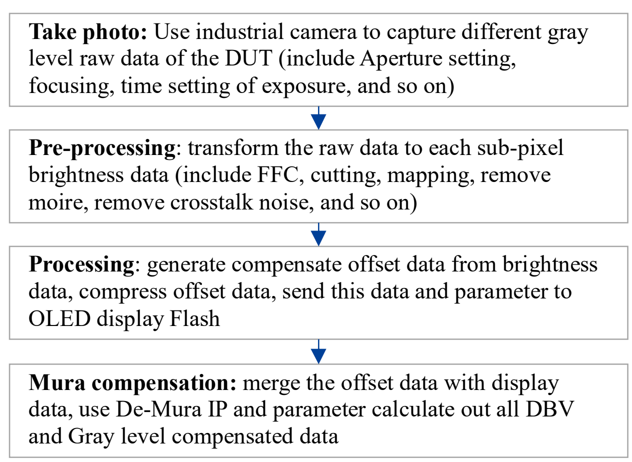

Fig. 1 Principle and flow of existing optical De-Mura

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2. Adaptive optics De-Mura

2.1 Analysis of Mura properties

The uneven display and vertical Mura are shown in Fig. 2 and Fig. 3. The causes of uneven display are mainly divided into two aspects: one is the brightness difference caused by IR Drop, which shows regular gradual changes along the ELVDD line direction, so the display data can be compensated by fixed rules [6]. The other is caused by process fluctuations, showing non-progressive changes, and there is no fixed law, so it needs to be compensated by optical De-Mura. Fig. 4 shows the photoelectric performance of uneven display at different gray levels. Mura degree is severe at both low and high gray levels and the brightness is reversed, intermediate gray levels Mura degree is slight or absent. The main causes of vertical Mura are substrate circuit design and the fluctuations of etching process. There are usually two manifestations: one is high frequency vertical Mura, and the spacing of Mura is about 5 pixels, which is distributed throughout the display; the other is that the spacing and width of Mura are not fixed, and only part of the area exists. Fig. 5 shows the photoelectric performance of vertical Mura at different gray levels. Mura degree is severe at low gray levels, and is slight or absent at medium and high gray levels. Table 1 is a summary of the photoelectric characteristics of uneven display and vertical Mura, the type and degree of Mura, and the optical De-Mura focused on compensation gray levels.

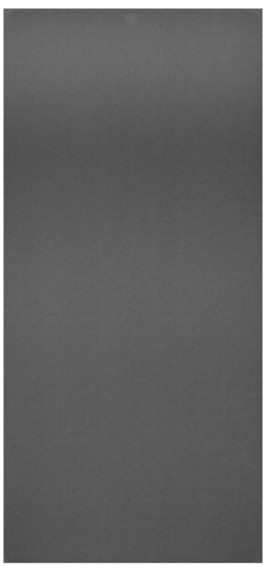

Fig. 2 Uneven display

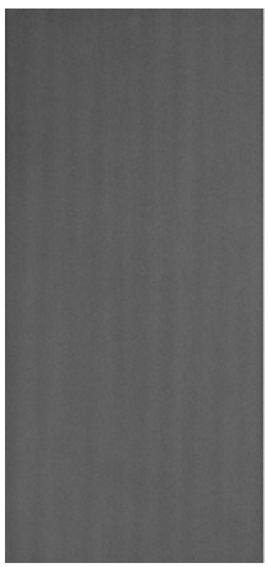

Fig. 3 Vertical Mura

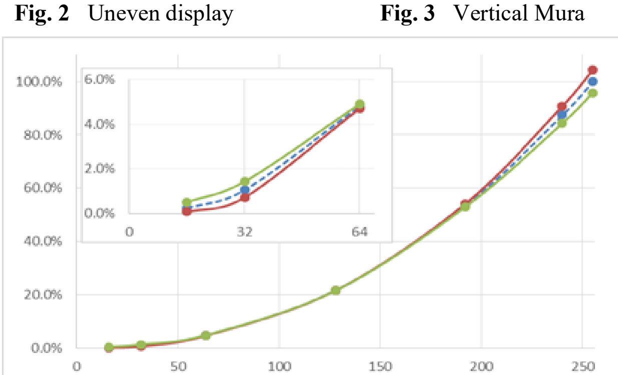

Fig. 4 Photoelectric curve of uneven display

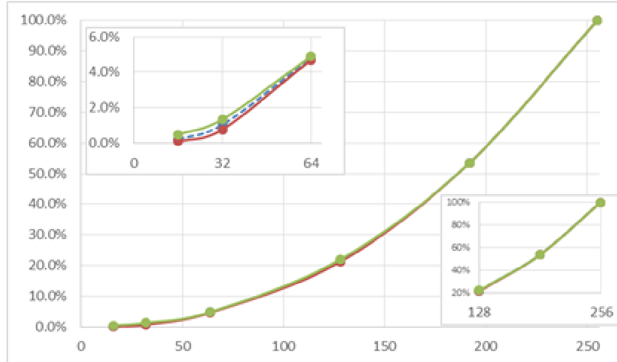

Fig. 5 Photoelectric curve of vertical Mura

Mura types	Low Gray levels	Median gray levels	High gray levels	Optical De-Mura compensation
Uneven display	severe	slight	severe	Low/High gray levels
Vertical Mura	severe	median	slight	Low gray levels

Table 1 Mura performance Summary

2.2 Model of Mura recognition

Image selection for Mura analysis. In order to quickly and accurately identify the types and degree of Mura, we only collect the data of the display at low gray levels based on the characteristics of these two types of Mura. To further simplify the analysis, we only analyze green monochrome pattern in the following Mura recognition model, since these two types of Mura are consistent in the Mura types and degree of RGB monochrome patterns.

Mura recognition model. Uneven display is low frequency Mura, and its Mura features are obvious, thus medium or high frequency vertical Mura has less interference to it. When establishing the Mura recognition model, we identify uneven display Mura first, and then identify vertical Mura. Fig. 6 shows the Mura recognition model. To remove the interference of noise, mean filtering and median filtering are used for the analysis of image data respectively. By dividing the data, the average brightness of different regions is obtained, and the maximum brightness difference of the average brightness of each region is calculated to characterize the type and degree of uneven display. To extract the vertical Mura features, we first remove the interference of uneven display, and then obtain the degree distribution map of vertical Mura by extracting and accumulating the vertical Mura boundaries. After that, we carry out partition processing to obtain the vertical Mura feature values of the severe area in the display and avoid the Mura degree being averaged with the whole data analysis. Finally, we use the standard deviation of the normal distribution to characterize the degree quantification value of the vertical Mura in each region, of which the maximum value can characterize the quantitative characteristics of the display vertical Mura.

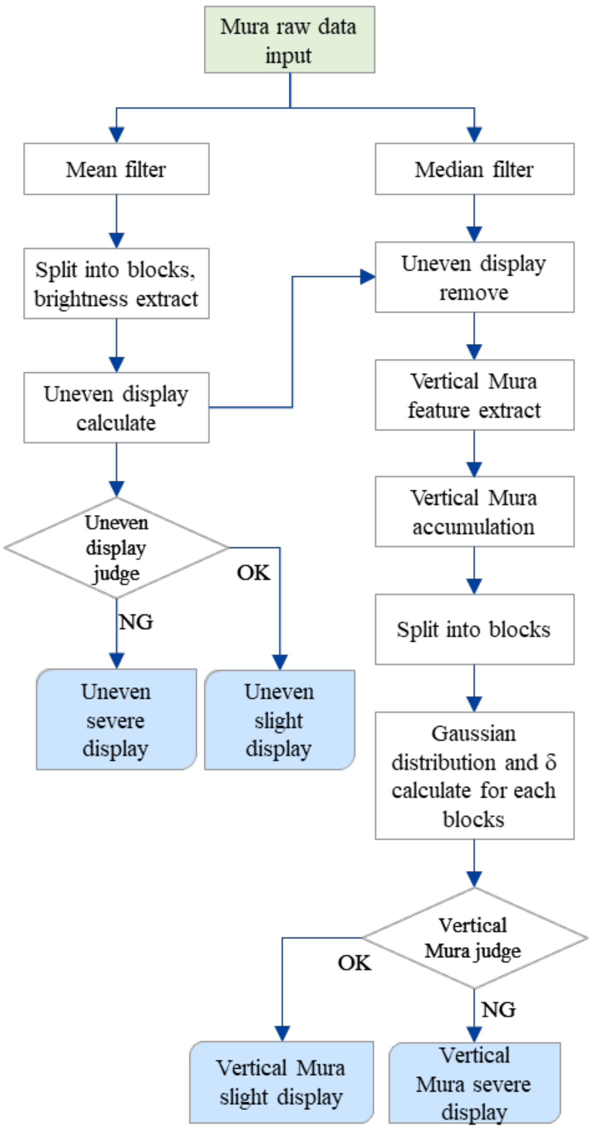

Fig. 6 Uneven display and vertical Mura recognition model

Uneven display identification. Fig. 7(a) is Mura with uneven display, and the data characteristics of uneven brightness are shown in Figure 7(b). Compared with products without uneven display, the data characteristics are shown in Fig. 7(c) and Fig. 7(d) respectively. Using formula (1), the quantitative characteristic value P1 of uneven display can be obtained: Lu_{max} refers to the maximum brightness value after partition normalization; Lu_{min} refers to the minimum brightness value after partition normalization, and Lu_{target} refers to the reference brightness value after partition, which is obtained from the mean value of the gamma calibration area.

$$P_1 = \frac{Lu_{max} - Lu_{min}}{Lu_{targrt}} \times 100\% \qquad (1)$$

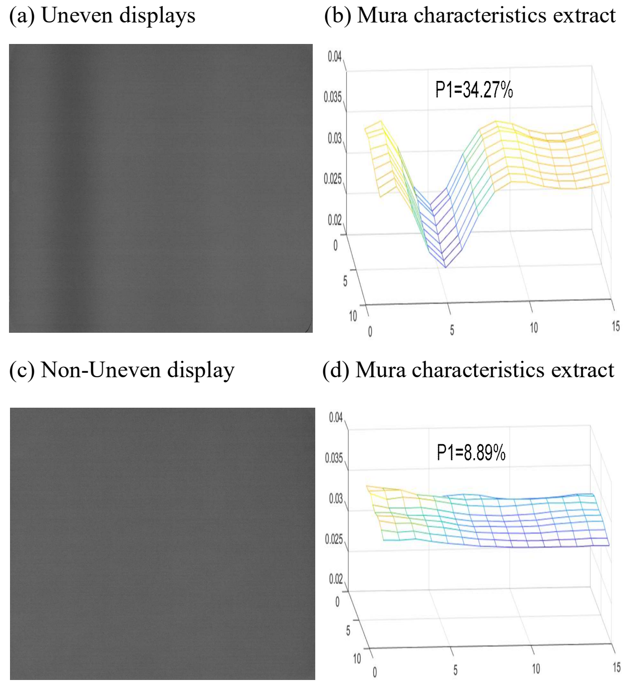

Fig. 7 Uneven display identification

Vertical Mura identification. Use formula (2) to remove the uneven display or other low-frequency Mura, where Lu'_{pixel} is the brightness data of each sub-pixel after removing low-frequency Mura, Lu_{median} is the brightness data of each sub-pixel after median filtering, Lu_{135} is the brightness data of each sub-pixel reconstructed by linear interpolation using the average brightness of each region after the uneven display partition, and Lu_{centre} is the average brightness value of the central region. Fig. 8(a) shows the vertical Mura, Fig. 8(b) shows the data after median filtering and removal of uneven display Mura, Fig. 8(c) shows the data after traversing the convolution using the vertical Sobel operator, and Fig. 8(d) shows the data after accumulation through convolution. The Sobel operator and cumulative convolution are selected as shown in Formula (3) and Formula (4), according to the performance of the two types of vertical Mura. Formula (5) is used to calculate the standard deviation δ of each region, and the maximum standard deviation δ is taken to obtain the quantitative feature value P2 of vertical Mura.

$$Lu'_{pixel} = Lu_{median} - Lu_{135} + Lu_{centre} \qquad (2)$$

$$g = \begin{bmatrix} Lu_{11} & Lu_{12} & Lu_{13} \\ Lu_{21} & Lu_{22} & Lu_{23} \\ Lu_{31} & Lu_{32} & Lu_{33} \end{bmatrix} * \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad (3)$$

$$g = \begin{bmatrix} Lu_{11} & Lu_{12} & Lu_{13} & Lu_{14} & Lu_{15} \\ \vdots & & \cdots & & \vdots \\ Lu_{51} & Lu_{52} & Lu_{53} & Lu_{54} & Lu_{55} \end{bmatrix} * \begin{bmatrix} 1 & 3 & 5 & 3 & 1 \\ \vdots & & \cdots & & \vdots \\ 1 & 3 & 5 & 3 & 1 \end{bmatrix} \qquad (4)$$

$$\delta = \sqrt[2]{\frac{\sum_1^n (Lx-\bar{L})^2}{n-1}} \quad (5)$$

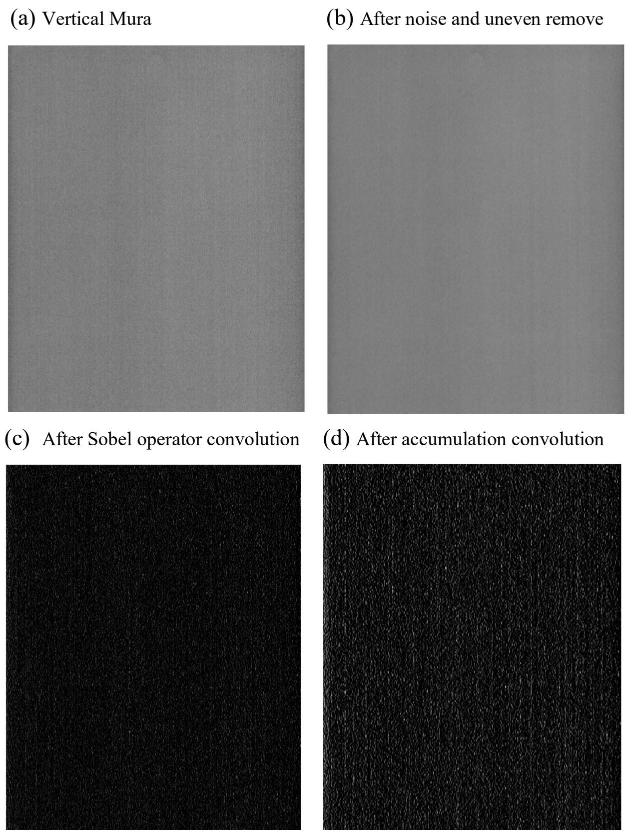

Fig. 8 Vertical Mura identification

In order to confirm whether the characteristic values obtained are correct, we made a hypothesis testing analysis for uneven display and vertical Mura. As shown in Figure 8, the P-levels of uneven display and vertical line Mura are both greater than 0.05, which means that type and degree can be recognized accurately.

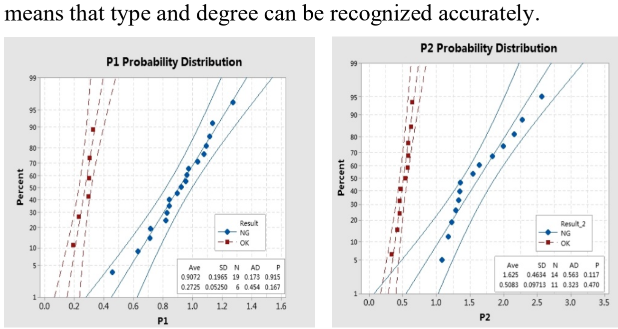

Fig. 9 Hypothesis testing analysis for uneven display and vertical Mura

1.3 Application in project

Compared with the existing optical De-Mura, adaptive optics De-Mura needs to identify Mura type and degree first, as shown in Figure 6, and then matches appropriate optical De-Mura setting according to the classification shown in Table 2. We apply this scheme in projects, where the uneven display characteristic value P1 is limited to 0.5, and the recognition accuracy is estimated at 98.07%. Meanwhile, the recognition accuracy of vertical Mura characteristic value P2 is estimated at 97.05% and limited to 0.75. As a result, the mass production yield has been improved by 1.5%, and the total compensate ability has also been improved significantly.

Uneven display	Vertical Mura	Optic De-Mura compensation method		
		Take photo(gray level)	Pre processing/ Processing	Demura IP
Slight	Slight	Low/middle	Normal	Normal interpolation Normal gain
Severe	Slight	Low/high	Intensify low frequency Mura	Optimize interpolation Optimize gain
Slight	Severe	Low/middle	Intensify high frequency Mura	Optimize interpolation Optimize gain
Severe	Severe	Low/High	Normal	Optimize interpolation Normal gain

Table 2 Appropriate optical De-Mura setting

3. Conclusion

In this paper, we have established an approach to categorize the Mura type and degree feature recognition model of uneven display and vertical Mura in OLED displays, in which an appropriate optical De-Mura scheme have been selected. Through a large number of product verifications, the processes have been proved to be effective, and the yield and compensate ability of optical De-Mura have significantly improved. Considering that OLED is one of the most promising display technologies, various types of Mura problems will become more prominent in the accompaniment of the application of CFOT, MLP, SLOD， as well as other emergent display technologies such as Si-based OLED, QD-OLED, and we believe that this methodology will be more widely used.

4. References

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