Mura Visual Simulation System and Quantitative Evaluation Criteria

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Abstract

Mura degrades the image quality of displays. In this paper, we introduce a novel mura visual simulation system that enables us to predict image quality and quantitatively evaluate mura, thereby significantly improving the efficiency of mura improvement efforts.

Author Keywords

Mura; Uniformity; Color coordinate; Gray variance.

1. Introduction of mura

Mura, characterized by uneven brightness and color distribution, significantly affects display quality. Figure 1 is the image of mura. In theory, factors such as differences in Vth (threshold voltage), Rc (resistance and capacitance), and Cst (storage capacitor) between pixels lead to variations in brightness on a micro scale. As a result, macroscopic defects appear and mura becomes visible on the panel [1].

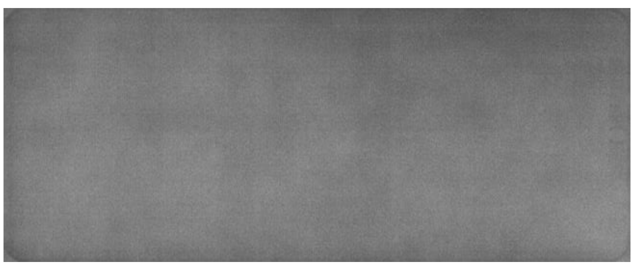

Figure 1. Mura photograph

2. Mura visual simulation system

We established a mura visual simulation system utilizing Empyrean Aether FPD, Light Tools, Matlab and Ansys Speos. We also proposed a quantitative evaluation criterion for mura. It comprises an electrical simulation system, an optical simulation system, and a mura quantitative evaluation system. Figure 2 shows the mura visual simulation process. First, we output the current differences between pixels. The simulation must account for the influence of process parameter fluctuations on membrane characteristics. Next, we convert the current data into EL brightness, create a 3D model of the panel, and configure the model with the EL luminous power derived from the conversion. Then, we perform ray tracing and output visual images through an imaging process. Third, we calculate the grayscale variance or color variance. A smaller variance indicates better lightness and color uniformity.

2.1 Electrical simulation system

Based on the electrical simulation system, we can evaluate the influence of electrical factors on the current differences between pixels (Figure 3). It is widely believed that the charging speed at node N4, voltage fluctuations at node N1, and fluctuations in Vth and SS (sub-threshold swing) have significant effects on EL luminance uniformity, resulting in low gray mura [2] (Figure 4).

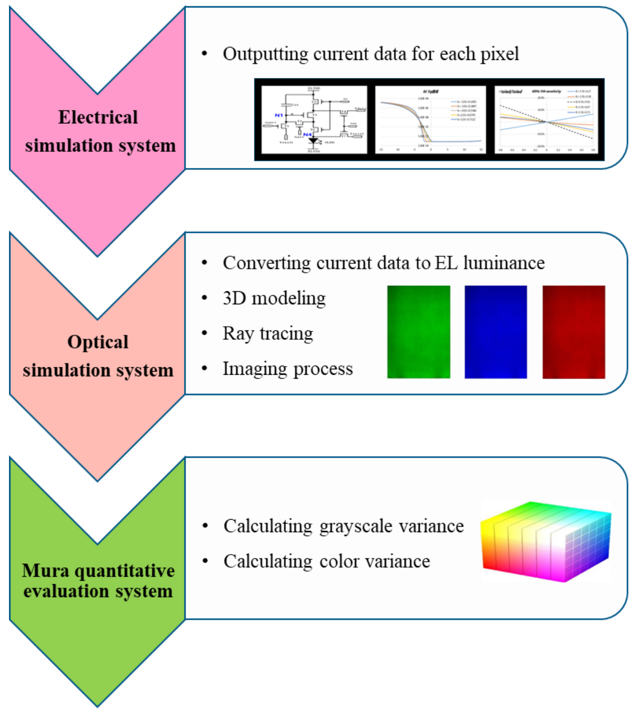

Figure 2. Mura visual simulation process

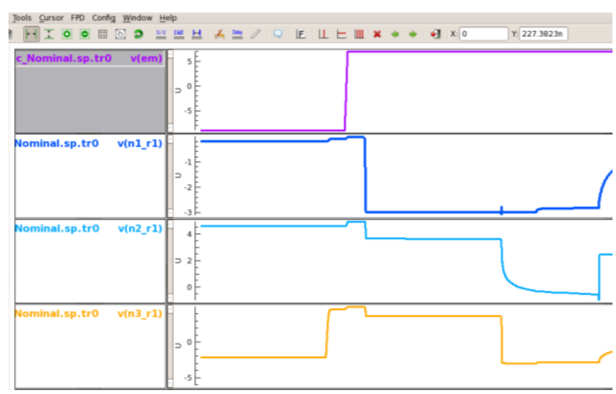

Figure 3. Electrical simulation system

2.2 Optical simulation system

We can proceed with the visual optical simulation based on the electrical simulation data. Figure 5 shows the optical simulation system. The process involves the following steps: First, convert current data into EL luminance values for different micro-scale regions. Second, create a 3D model based on the pixel design and panel's film stack. Third, set the luminous properties of the RGB pixels based on the luminance data obtained in the first step. Fourth, arrange the pixels to display the intended content.

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Fifth, perform ray tracing. Finally, conduct image processing [3][4].

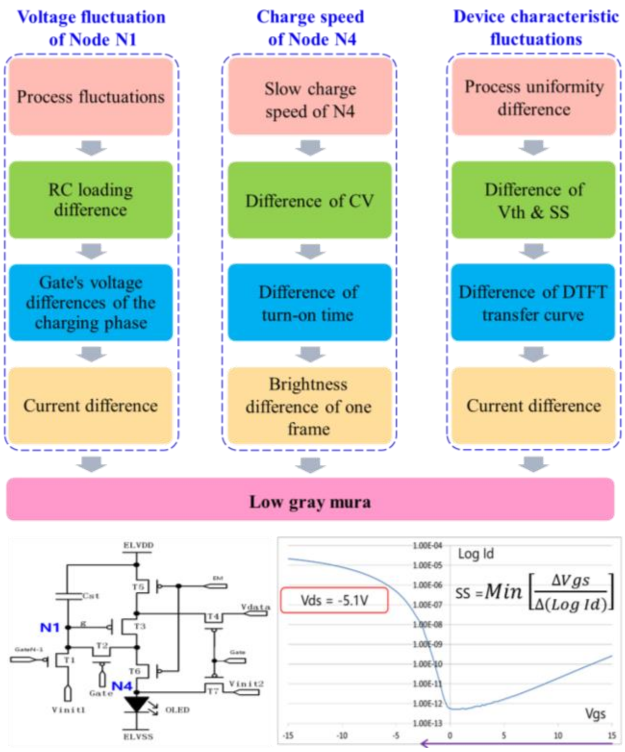


Figure 4. Electrical factors on low gray mura

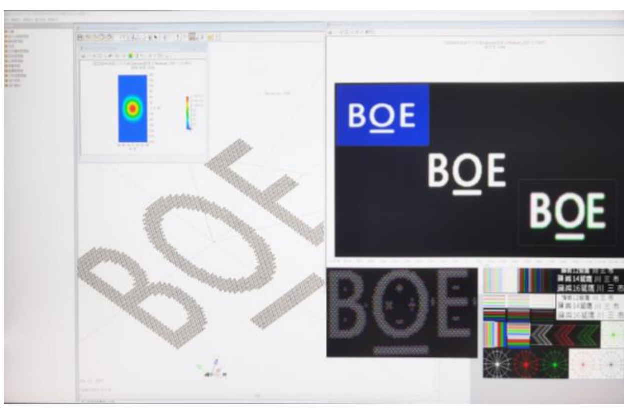


Figure 5. Optical simulation system

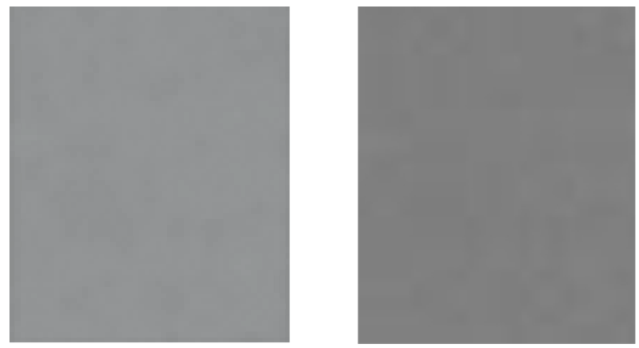
By following the previous three simulation steps, we can obtain visualized images of mura (Figure 6). It is evident that the lightness uniformity of the simulation image resembles that of the actual mura photograph on the display.

Due to the limited computing power of simulation, we are currently unable to conduct electrical simulations with larger areas or more pixels. If the subsequent hardware performance is sufficiently improved, we will be able to complete the electrical simulation on the entire panel, in which case a simulation image that is closer to the actual mura photograph can be obtained. Actually, by setting the pixels' luminance based on the lightness distribution data captured by the de-mura camera rather than using simulation data, we can obtain a visual simulation picture that matches the photograph very well using the optical simulation system (Figure 7).

2.3 Mura Quantitative Evaluation System

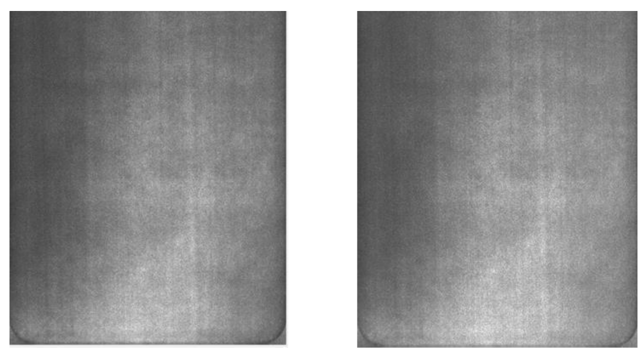
2.3.1 Lightness uniformity quantitative evaluation

After outputting the mura simulation picture, we can perform a quantitative evaluation of the mura. Since it is currently challenging to obtain mura simulation pictures of large areas, we assess the effectiveness of the quantitative evaluation system using actual mura photographs. Figure 8 shows the process. First, obtaining the mura picture from simulation or capturing a mura picture with a camera. Second, extracting the grayscale data using programming techniques. Third, calculating the grayscale variance. We use L_{mura} to represent grayscale variance. In the formula, Gray represents the grayscale value of pixels, and n represents the total number of pixels in the image. The smaller the L_{mura} value, the less severe the mura.



Simulation picture　　Mura Photograph

Figure 6. Simulation picture and mura photograph



Simulation picture　　Mura Photograph

Figure 7. Simulation picture based on the lightness distribution data captured by de-mura camera

Usually, there are two ways to evaluate mura. The first one is subjective judgment by the human eye, and the other one is testing lightness or color data with optical equipment. The accuracy of these traditional methods is not sufficiently high, and misjudgments can occur.

Due to psychological factors, different people may have varying judgments about mura, and the same person may even have different judgments at different times. Figure 9 is the visual quantitative data of mura. Although the testers determined that the severity of mura was the same between sample 2 and 3, in fact, we can see that sample 3 had more severe mura based on the photograph. Conversely, the L_{mura} value outputted by the quantitative evaluation system shows that the variance of sample 3 is larger, which means its lightness uniformity is worse. It is evident that the data from the mura quantitative evaluation system corresponds more closely with the photograph.

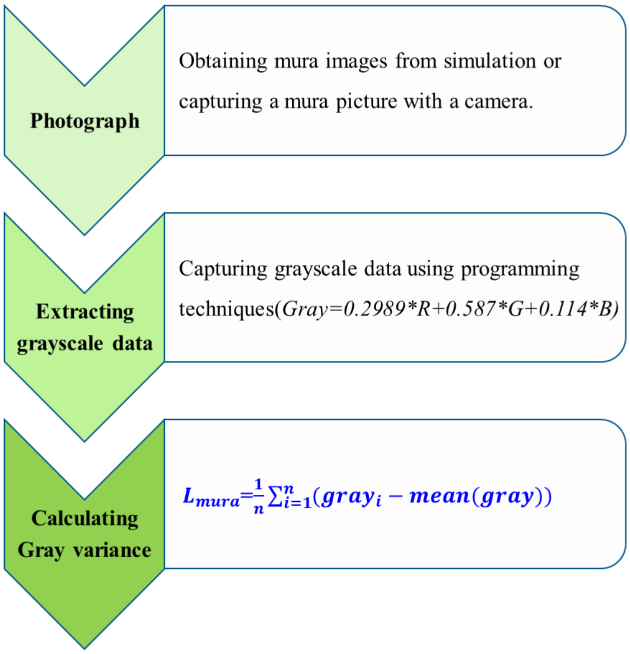


Figure 8. Lightness uniformity quantitative

Sample	Mura Photograph	Manual judgment	L_{mura}
1		L1.0	7.877
2		L1.5	9.811
3		L1.5	11.376

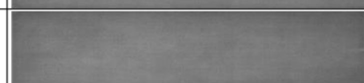
Figure 9. Visual quantitative data of mura

Upon comparison, we found that the mura quantification system provides higher accuracy. Figure 10 presents a comparison of mura visual quantification data with delta E5 measured data. It can be seen that the delta E5 value for sample 2 is slightly higher than that for sample 5. In fact, based on the photograph, it is evident that the lightness uniformity of sample 2 is significantly worse. However, the L_{mura} value indicates that the data for sample 2 is significantly higher than that for sample 5, which aligns more closely with the photograph.

The reason the mura quantitative evaluation system's data is more accurate is that Delta E5 was measured using equipment that only captured the lightness at 135 points to calculate uniformity (Figure 11), while the mura quantitative evaluation system can set as many sampling points as needed. For example, the L_{mura} value in Figure 10 was calculated using 5,400,000 points.

2.3.2 Color uniformity quantitative evaluation

The mura quantitative evaluation system can also evaluate color uniformity. Figure 12 shows the process. First, obtaining the mura picture from simulation or capturing a picture of mura. Second, extracting the RGB data using programming techniques. Third, converting to color tristimulus values. Fourth, converting to the xyz color space. Fifth, calculating color uniformity. We use C_{mura} to represent color variance. The smaller the C_{mura} value, the better the color uniformity. Figure 13 shows the comparison between color visual quantification data and manual judgment results. Although the tester determined that samples 3 and 4 have the same color uniformity, we can observe from the photograph that sample 4 is superior. However, the C_{mura} value indicates that the data for sample 3 is higher, which means its color uniformity is worse. It is evident that the data from the mura quantitative evaluation system correspond more closely with the photograph.

Sample	Photograph	Delta E5	L_{mura}
1		18.516	66.170
2		40.852	352.807
3		23.252	70.647
4		28.971	96.223
5		33.732	103.062
6		19.726	92.414

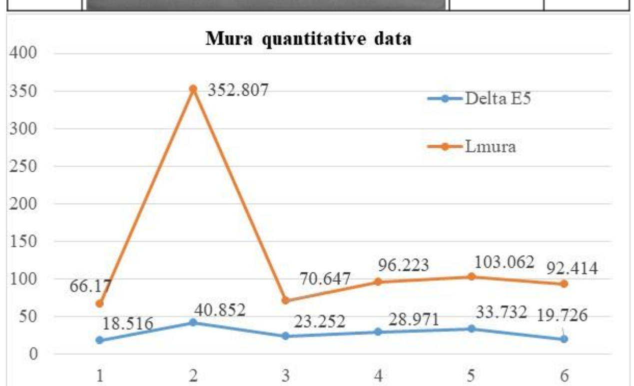


Figure 10. Mura visual quantification data and delta E5 measured data

2.3.4 Automated calculation application for mura quantification

To enhance the efficiency of mura quantification, we have developed an automated calculation application. With this application, even those without programming expertise can quickly calculate the quantitative data of mura (Figure 14).

So far, we have completed the preliminary development of the mura visual simulation system. In the next step, we will further optimize the electrical simulation system to acquire larger samples of electrical data.

3. Conclusion

Using the mura visual simulation system and quantitative evaluation criteria, we can evaluate the impact of electrical design and process fluctuations on display quality both qualitatively and quantitatively. This approach helps us save considerable time and cost that would otherwise be spent on manufacturing and experiments. It will play a significant role in mura evaluation, image quality improvement, and other related tasks.

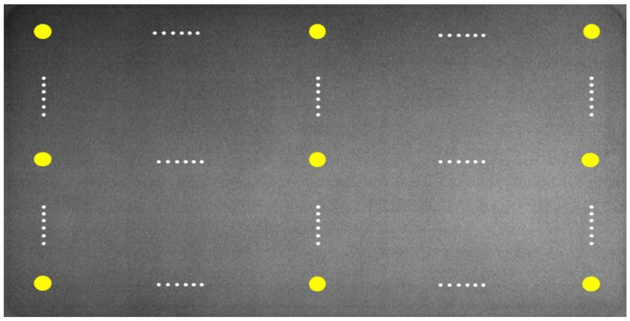


Figure 11. Test point of delta E5

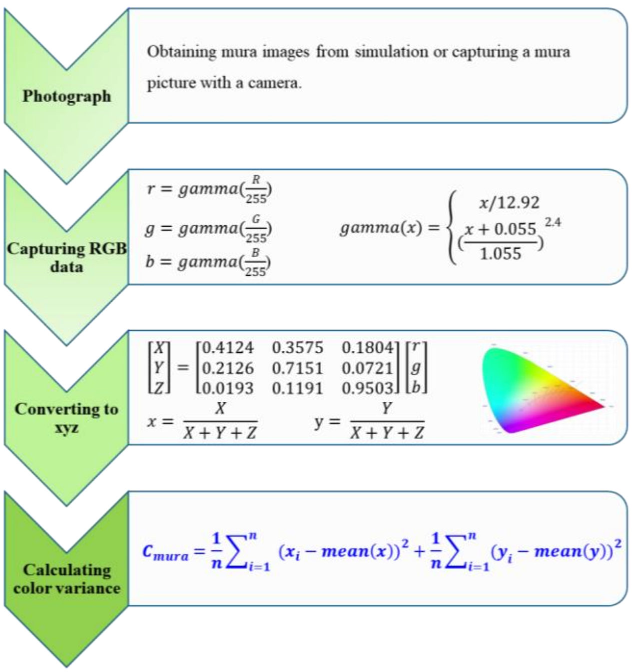


Figure 12. Color uniformity quantitative process

4. Acknowledgements

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5. References

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Sample	Mura Photograph	Manual judgment	C_{mura}
1		Level 4	155.45
2		Level 1.5	34.68
3		Level 0.5	8.78
4		Level 0.5	1.73

Figure 13. Color uniformity quantitative data

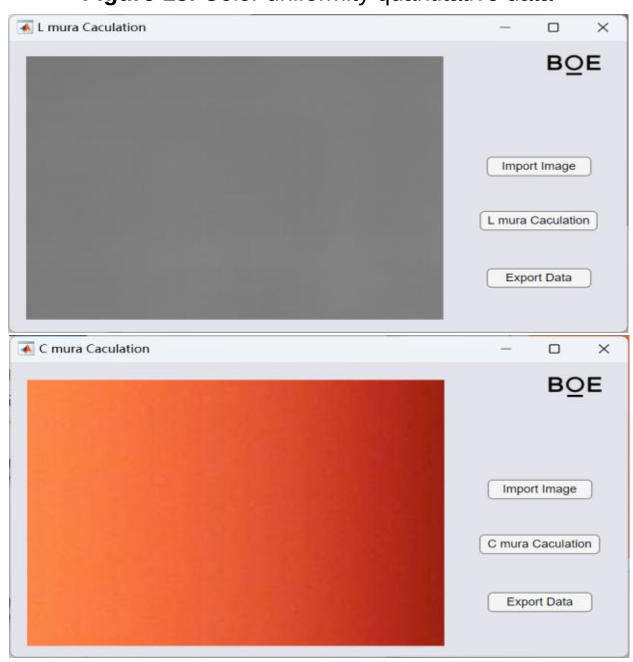

Figure 14. Mura quantitative characterization application