The Measurement of Optical Properties for Curved Displays
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ABSTRACT
Luminance and ambient contrast ratio (ACR) are two of the most important optical properties of displays. This paper presents the modifications of traditional photometry measurement methods to increase the measurement accuracy of the above two parameters for the curved display.

INTRODUCTION
Many companies and institutes involve in developing flexible display as these kinds of products are expected to become future tendency. With this development trend, there is the demand of new measurement methods as the current methods for evaluating the optical performances of flat display need to be modified to fulfil the characteristics of these new types of products. As a curve is the most common shape of flexible products, this paper focuses on the new measurement techniques for two of the most important optical properties, luminance uniformity and ambient contrast ratio, of curved displays.

Uniform luminance distribution is the basic requirement for a good quality display. Measuring the luminance at several specified points on the display may not be able to faithfully represent the uniformity of the whole display. Nevertheless scanning the luminance across the display is time-consuming especially for large-scale displays. To avoid the insufficiency of specified points method and the inconvenience of scanning method, image luminance measurement device (ILMD) may therefore be preferred. However measuring the image luminance of curved display with flat field calibrated ILMD, the measured results deviate from the real values and the deviation is larger as the radius of curvature of the display is smaller or the display is less like a Lambertian source. To increase the luminance measurement accuracy of ILMD for curved display, a correction factor is employed.

(1)

To verify the practicability of $F_L$, a white color EL flexible surface source with convex curve is used as the test sample. The radius of curvature of the test sample is 85 mm. Figure 1 demonstrates the image luminance measured by ILMD with and without multiplying $F_L$. Figure 1, comparing with the $\omega-Y$ distribution measured by the scanning...
method, the luminance measured by ILMD for the convex curved source is usually getting lower and lower as the position moving closer and closer to the edge of the curved source. After multiplying $F_L$, the corrected result is much closer to the $\omega$–$Y$ distribution. Therefore the correction factor $F_L$ presented in equation (1) is able to improve the luminance measurement accuracy of ILMD and make the $\omega$–$Y$ luminance distribution for the curved display can be estimated by the image luminance.

Fig. 1. Red line is the results measured by the ILMD. Green line is the results of red line multiplying the correction factor $F_L$. Blue line is the results measured by the point scanning method.

2. Ambient Contrast Ratio-reflectance measurement by integrating sphere

Figure 2 is the schematic diagram of reflectance measurement by placing both the test sample and reference white plate in an integrating sphere simultaneously to maintain a similar effective reflectance inside the sphere during measurement. Although the practicability of this method is limited by the size of the test sample, its advantage is saving the inconvenience of preparing different sample ports for different curvatures of the samples. Nevertheless, the shape of the concave curved sample blocks part of light illuminating on itself and causes non-equivalent illumination on reference plate and itself. This non-equivalent effect induces significant measurement error especially when the test sample has small curvature.

Assume the radiant intensity from each point of the sphere wall is uniform and the sphere wall is a Lambertian surface. The irradiance $E_\theta(\lambda)$ at the flat reference surface can be described by equation (2) where $I_0$ is radiant intensity from each interior point on the sphere wall in a direction normal to the sphere surface.

$$E_\theta(\lambda) \propto I_0(\lambda) \int_0^{\frac{\pi}{2}} \cos \theta_f \sin \alpha_f \, d\alpha_f \, d\theta_f \, d\tau_f = 4 I_0(\lambda)$$

(2)

In contrast to the flat reference surface, not only the flux from the sphere wall but also the reflected flux from the concave curved surface itself illuminate the centre of the curved surface. The irradiance caused by the flux from the sphere wall ($E_{Cc0}$) and concave curved surface ($E_{cc0}$) can be expressed as

$$E_{Cc0}(\lambda) \propto I_0(\lambda) k_{Cc,ave}(x, y, z) \frac{A(\lambda)}{1 - A(\lambda)}$$

(3)

where

$$A(\lambda) = \frac{2 \rho_c(\lambda)}{\pi} \int_0^{\frac{\pi}{2}} \int_0^{\frac{\pi}{2}} (\cos \theta \sin \alpha)^{1+\theta} d\theta d\alpha$$

$$+ \int_0^{\frac{\alpha_0}{\theta_0}} \int_0^{\frac{\pi}{2}} (\cos \theta \sin \alpha)^{1+\theta} d\theta d\alpha$$

$g$ and $\rho_c$ are the distribution index and reflectance of the curved surface, respectively. $\alpha_0$ and $\theta_0$ are the parameters depending on the radius of curvature and size of the curved surface.

To compensate the non-equivalent amount of irradiance illuminating on the flat standard plate and test concave curved display, the correction factor $F_p$ is equal to $E_f/(E_{Cc0}+E_{cc0})$.

To verify the accuracy and effect of $F_{ref}$, a 20 cm $\times$ 5 cm flexible OLED is adopted as the test sample. Firstly, bend the sample from flat to convex curve and measure its reflectance for different shapes. The experimental results show that the reflectance of convex curve is only slightly smaller than that of the flat shape. This illustrates that the reflectance of this sample will not significantly change when bending it into a convex curve and there is no difference in illumination of the convex curve and the flat reference plate. Therefore, there is no need of correction for convex curved sample.

Nevertheless, the situation is quite different for concave curve. Figure 3(a) shows the measurement results by bending the test sample to concave curve. The measurement results are strongly depending on the curvature as the smaller the radius of the concave sample the more of light is blocked by the sample itself, which results in larger measurement error. To reduce the error by applying $F_p$, firstly substitute the original reflectance measured results into equation (3) for 1st correction.
Then use the reflectance of 1st correction for 2nd correction. From figure 3, it is clear that the deviations are greatly reduced from 14% to within ±2%.

![Fig. 3](image)

Fig. 3 (a) The original reflectance measurement results for concave curves. (b) and (c) and corrected results after 1st and 2nd correction, respectively.

3. Conclusions

Traditional photometry measurement methods may not be suitable for the curved display in some cases. To increase the measurement accuracy, correction factors for image luminance and ambient contrast ratio measurement are developed and verified in this paper. The calculation of the correction factors can be built-in the data analysis software for the convenience of use.

References