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Determining an Optimal Display Module-Level White Point Target for a Display Module

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Determining an Optimal Display Module-Level White Point Target for a Display Module

Abstract:

This publication describes techniques for determining an optimal display module-level white point target for a display module considering a device-level white point calibration brightness drop. In aspects, a distribution of display modules includes a distribution of module-level white points that are centered around a module-level white point target. A computing device manufacturer fits a two-dimensional Gaussian function to the distribution and calculates an average brightness drop for the distribution once calibrated to a device-level white point target. Using the Gaussian function, the manufacturer recalculates the average brightness drop for a shifted distribution. The manufacturer repeats this process until an optimal module-level white point target that includes a minimum average brightness drop is determined. The manufacturer includes a new distribution of display modules centered around the optimal module-level white point target in computing devices that have a display. Thus, after device-level white point calibration, the average brightness drop in the computing devices is minimized.

Keywords:

display, color calibration, white point, brightness, drop, power efficiency, liquid crystal display (LCD), International Commission on Illumination (CIE), CIE XYZ, RGB, color space

Background:

To achieve consistent color reproduction throughout computing devices that include a display (e.g., smartphones, tablets), a manufacturer may use white point calibration. Typically, the manufacturer accomplishes white point calibration for a display (e.g., a display module) by lowering an intensity of at least one of three primary color channels, which include red, green, and blue. However, unless a module-level white point is equivalent to a device-level white point target, the display may suffer from a brightness drop. The brightness drop problem is significant for liquid crystal displays (LCDs) because backlight power remains unchanged, resulting in a power efficiency loss. The power efficiency loss problem is further exacerbated when backlight power is increased to achieve a same brightness for the LCD before white point calibration.

The computing device manufacturer may attempt to alleviate these problems by setting a module-level white point target equal to the device-level white point target. By so doing, a distribution of display modules include a distribution of module-level ("native") white points centered around the device-level white point target. However, this approach does not result in a lowest average brightness drop for the display modules because the distribution of module-level white points is not optimally tight, and an amount of brightness drop is strongly dependent on native color distance and direction to the module-level white point target. Figure 1 illustrates examples of the brightness drop problem, which coincides with the power efficiency loss problem, for a distribution of native white points.

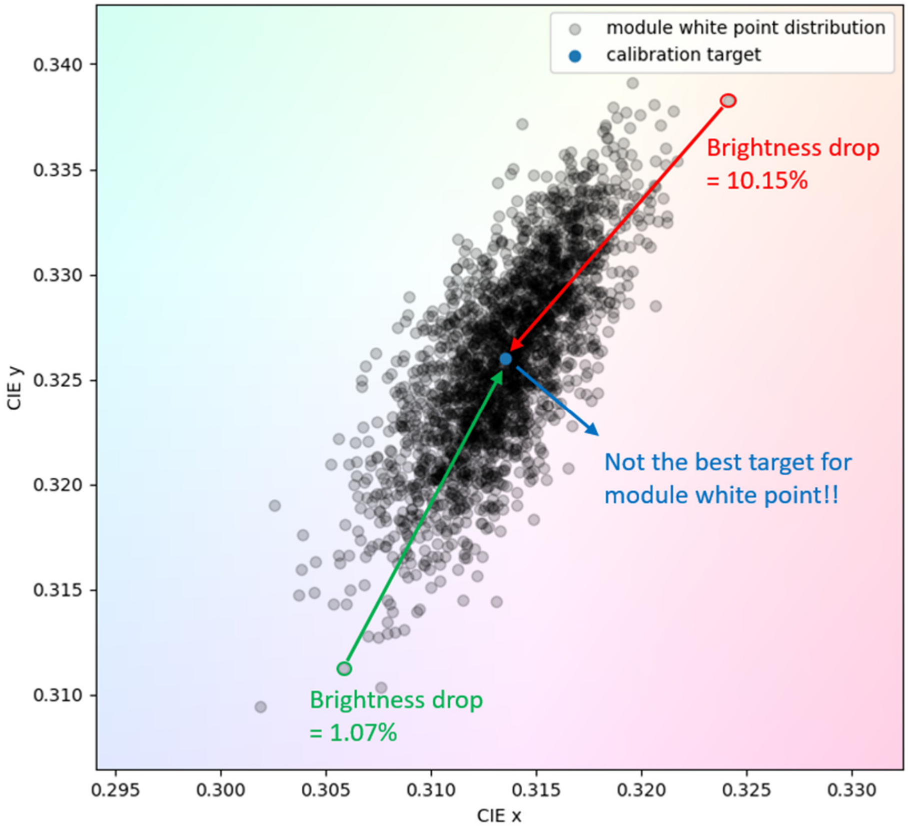

Figure 1

As illustrated, Figure 1 is a plot of International Commission on Illumination (CIE) y values against CIE x values. Figure 1 includes the distribution of module-level white points (“module white point distribution”) in grey, the module-level white point target (“calibration target”) in blue, a first brightness drop in green, and a second brightness drop in red. The distribution of module-level white points is centered around the module-level white point target at CIE coordinate (0.3135, 0.3260). The first brightness drop for a first display module is 1.07 percent (%), as illustrated, and the second brightness drop for a second display module is 10.15 %. Although the first and second display modules are approximately a same color distance from the module-level white point target, the second brightness drop is an order of magnitude larger than the first brightness drop.

The amount of brightness drop is strongly dependent on not only the color distance to the module-level white point target, but also the color direction. The native white point of the first display module is in a lower left of the plot, where displays are considered "cool," or tinted blue (e.g., the blue primary color channel is dominant). For white point calibration, the intensity of the blue primary color channel is reduced for the first display module. The native white point of the second display module is in an upper right of the plot, where displays are considered "warm," or tinted yellow (e.g., a mix of the red and green primary color channels are dominant). For white point calibration, the intensities of the red and green primary color channels are reduced for the second display module. The green primary color channel contributes to most of a brightness of a display and, therefore, the second display module suffers a significantly larger brightness drop than the first display module.

Description:

This publication describes methods for determining an optimal module-level white point target considering device-level white point calibration brightness drops. The methods include a mathematical approach to predict a brightness drop ratio caused by white point calibration. The mathematical approach relies on native white, red, green, and blue CIE x-y coordinate values. Equation 1 defines, for a given display module, an intensity ratio S for the three primary color channels (e.g., RGB).

$$\begin{bmatrix} S_r \\ S_g \\ S_b \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix}^{-1} \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix} \tag{1}$$

The intensity ratio S for the display module is a three-by-one matrix that is a dot product of the transpose of a first matrix and a second matrix. The first matrix is a three-by-three matrix and includes *X*, *Y*, and *Z* values for native red, green, and blue colors of the display module, which are indicated by subscripts *r*, *g*, and *b*, respectively. The second matrix is a three-by-one matrix and includes *X*, *Y*, and *Z* values for a native white color of the display module, which is indicated by a subscript *w*. Equation 2 defines the *X* value, Equation 3 defines the *Y* value, and Equation 4 defines the *Z* value.

$$X = \frac{x}{y} \tag{2}$$

$$Y = 1 \tag{3}$$

$$Z = \frac{1-x-y}{y} \tag{4}$$

In Equation 2, the *X* value for the display module is a quotient of a CIE *x* value is divided by a CIE *y* value. In Equation 3, the *Y* value for the display module is normalized to one (1). In Equation 4, the *Z* value for the display module is a quotient of a difference of 1, the CIE *x* value, and the CIE *y* value, divided by the CIE *y* value. In white point calibration for the display module, the CIE *x* and *y* values for the primary colors remain unchanged because only the intensities of the primary colors are being reduced. Therefore, new *X'*, *Y'*, and *Z'* values for the native white color of the display module can be substituted into Equation 1 to calculate a new intensity ratio *S'*. Equation 5 defines the new intensity ratio *S'* of the display module after white point calibration.

$$\begin{bmatrix} S'_r \\ S'_g \\ S'_b \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix}^{-1} \begin{bmatrix} X'_w \\ Y'_w \\ Z'_w \end{bmatrix} \tag{5}$$

Equation 5 is Equation 1 with the new *X'*, *Y'*, and *Z'* values for the native white color of the display substituted in for original *X*, *Y*, and *Z* values. The intensity ratio *S* before white point calibration and the new intensity ratio *S'* after white point calibration for the display module is used to define an RGB intensity ratio. Equation 6 defines the RGB intensity ratio *P* for the display module before and after white point calibration.

$$[P_r, P_g, P_b] = \frac{\left[\frac{S'_r}{S_r}, \frac{S'_g}{S_g}, \frac{S'_b}{S_b}\right]}{\max\left(\frac{S'_r}{S_r}, \frac{S'_g}{S_g}, \frac{S'_b}{S_b}\right)} \tag{6}$$

In Equation 6, the RGB intensity ratio *P* for the display module is an array of three values, one for red, green, and blue. The RGB intensity ratio *P* is a quotient of a matrix of three values divided by a maximum of the three values. The three values include quotients of the new intensity ratios *S'* after white point calibration divided by the intensity ratios *S* before white point calibration., one for each of the three primary colors. The RGB intensity ratio *P* is used to calculate a brightness drop percentage $\Delta Y\%$ for the display module after white point calibration. Equation 7 defines the brightness drop percentage $\Delta Y\%$.

$$\Delta Y\% = \left(1 - \frac{P_r S_r + P_g S_g + P_b S_b}{S_r + S_g + S_b}\right) * 100 \tag{7}$$

In Equation 7, the brightness drop percentage $\Delta Y\%$ is a product of 100 multiplied by a difference of one (1) subtracted by a quotient. The numerator of the quotient is a sum of products of the RGB intensity ratio *P* values multiplied by respective values of the intensity ratio *S* before white point calibration. The denominator of the quotient is a sum of the values of the intensity ratio *S* before white point calibration. For a module-level white point target (e.g., the calibration target in Figure 1), a heatmap of brightness drop percentages can be generated. Figure 2 illustrates the heatmap of brightness drop percentages for a module-level white point target at CIE x-y coordinate (0.3135, 0.3260).

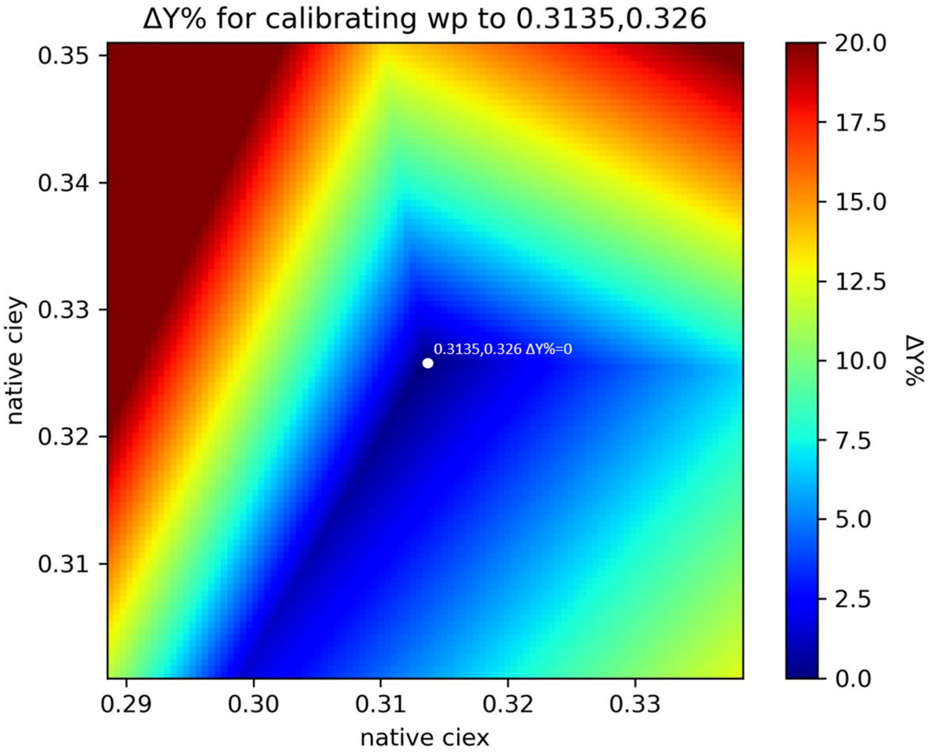

Figure 2

As Figure 2 illustrates, a display module having a module-level white point that resides within a blue portion of the heatmap will have a brightness drop of 0.0 % to 5.0 % after white point calibration to the module-level white point target. A display module having a module-level white point that resides within a light blue to light green portion of the heat map will have a brightness drop of 5.0 % to 12.5 % after white point calibration to the module-level white point target. A display module having a module-level white point that resides within a yellow to dark red portion of the heatmap will have a brightness drop of 12.5 % to 20.0 % after white point calibration to the module-level white point target. For a distribution of LCD modules (e.g., the distribution illustrated in Figure 1), a two-dimensional (2D) Gaussian fitting of their native white points can be overlayed onto the heatmap illustrated in Figure 2 to produce Figure 3.

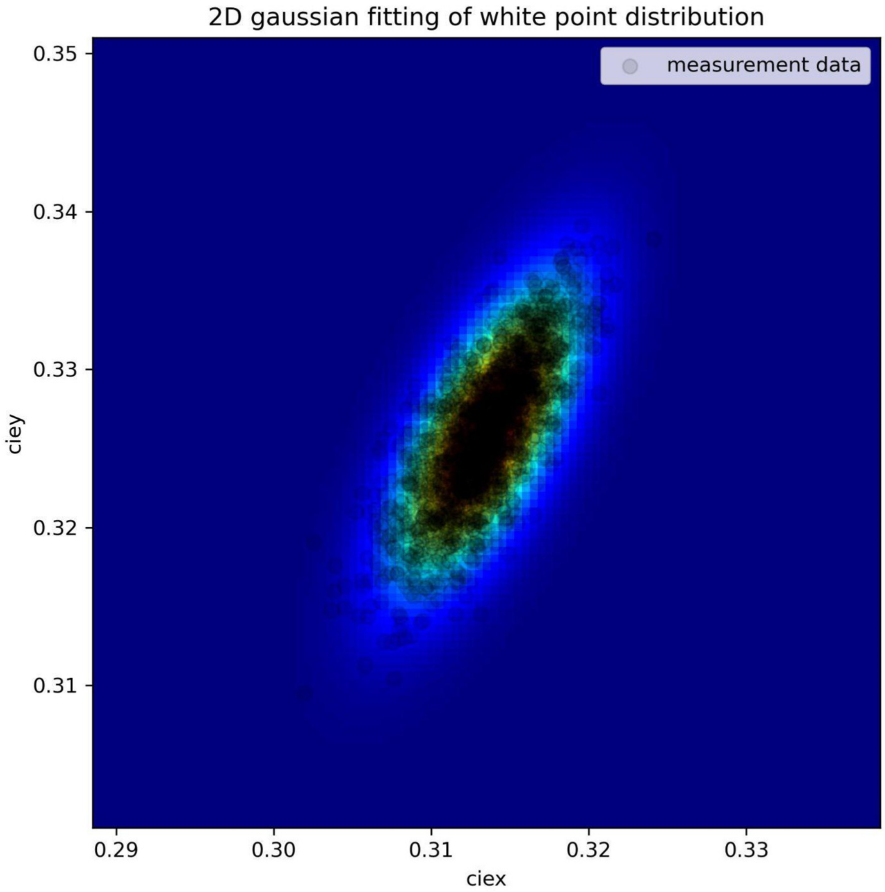

Figure 3

The 2D Gaussian fitting illustrated in Figure 3 is used to generally describe the native white points for the distribution of display modules. A mean vector and a covariance matrix for the 2D Gaussian fitting are defined in Equations 8 and 9, respectively.

$$Mean\ vector = \begin{bmatrix} W_{x\_avg} \\ W_{y\_avg} \end{bmatrix} \tag{8}$$

$$Covariance\ matrix = \begin{bmatrix} 1 & -0.75 \\ -0.75 & 1 \end{bmatrix} * 0.000025 \tag{9}$$

The mean vector in Equation 8 for the Gaussian distribution can be changed, which changes the typical value of a native white point, but the distribution remains the same. By so doing and overlaying the result on the heatmap in Figure 2, an optimal display module-level white point target is determined. The overlaying of the result on the heatmap in Figure 2 is illustrated by Figure 4.

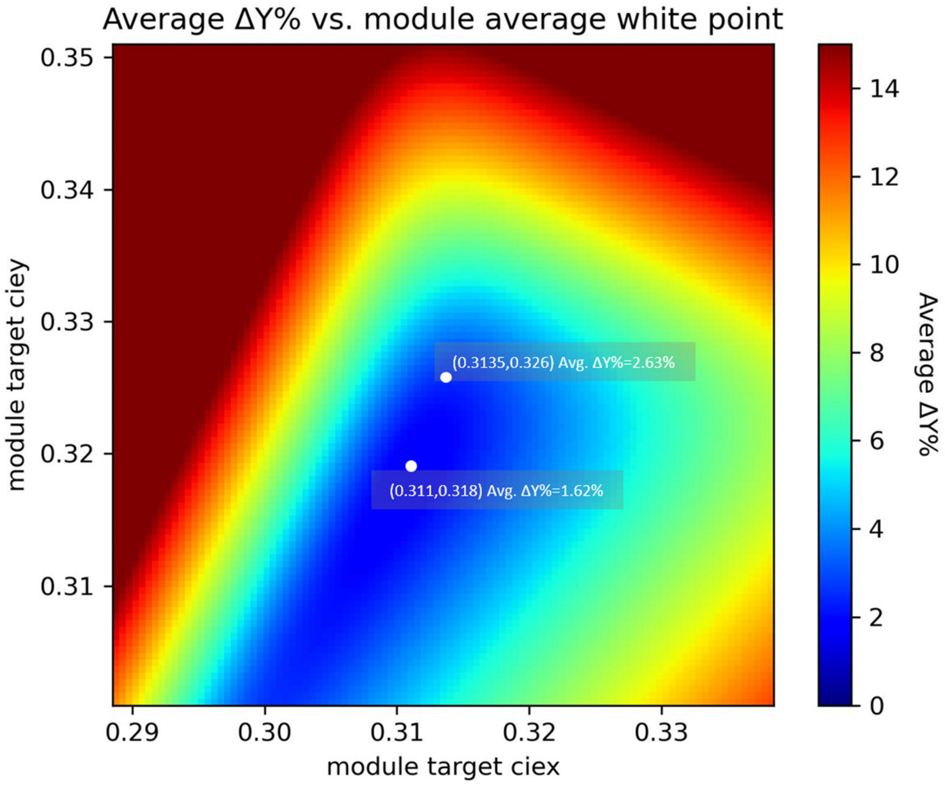

Figure 4

In Figure 4, the device-level white point target is an upper white point at CIE x-y coordinate (0.3135, 0.3260). If the module-level white point target is a same target, then an average brightness drop percentage Δ*Y%* for the distribution of display modules is 2.63 %. By changing the meant vector of the Gaussian distribution, however, the optimal module-level white point target is determined, which is a lower white point at CIE x-y coordinate (0.3110, 0.3180) in Figure 4. At this white point target, the average brightness drop percentage Δ*Y%* for the distribution of display modules is 1.62 %. This improvement in the average brightness drop percentage Δ*Y%* can be visualized more easily in a histogram illustrated in Figure 5.

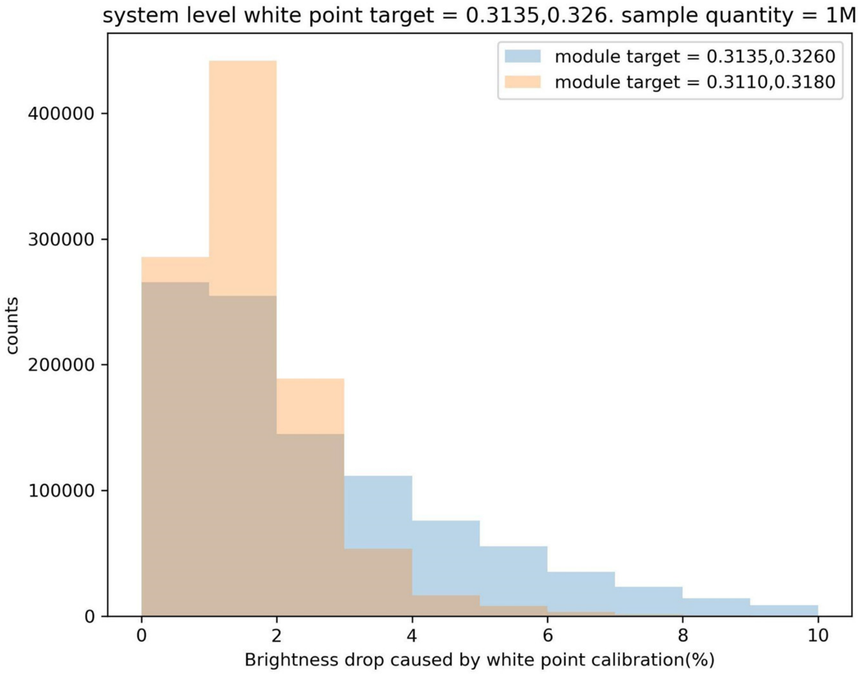

Figure 5

In Figure 5, blue bars in the histogram represent brightness drop percentages for the module-level white point target that is equivalent to the device-level white point target. Orange bars in the histogram represent brightness drop percentages for the optimal module-level white point target that is not equivalent to the device-level white point target. Not only does the average brightness drop percentage improve, but the distribution becomes tighter, reducing brightness variation between display modules. The optimal module-level white point target also significantly reduces display modules having a large brightness drop percentage, and therefore power efficiency losses, after white point calibration.

Once the computing device manufacturer determines the optimal module-level white point target, the manufacturer can acquire (e.g., in-house, from a display module vendor) a distribution of display modules whose module-level white points are centered around the optimal module-level white point target. The manufacturer may include this distribution of display modules whose module-level white points are centered around the optimal module-level white point target in computing devices. After calibrating the computing devices to the device-level white point, the manufacturer benefits from a lower average brightness drop, a lower variation in brightness between computing devices, and a lower average power efficiency loss.

References:

[1] Patent Publication: US20170140556A1. White Point Calibration and Gamut Mapping for a Display. Priority Date: April 12, 2016.

[2] Patent Publication: US20200051225A1. Fast Fourier Color Constancy. Priority Date: November 14, 2017.

[3] Patent Publication: US20170098429A1. Method for Producing a Color Image and Imaging Device Employing Same. Priority Date: December 19, 2016.

[4] Patent Publication: US20130314447A1. Method and Apparatus for Display Calibration. Priority Date: May 22, 2012.

[5] Hohmann, K. and Weber, M. (2018), Performance Optimization for In-Vehicle Displays. Information Display, 34: 6-10. https://doi.org/10.1002/j.2637-496X.2018.tb01098.x, https://sid.onlinelibrary.wiley.com/doi/pdf/10.1002/j.2637-496X.2018.tb01098.x.