Innovative Industrial Displays with Enhanced Gamut of a Colorful Image of Three Components

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Abstract. The task how to define tristimulus coordinates of the screen gamut in \(xy\)-plane with color formation scheme of three components is being studied. To solve this task is practically important to improve the manufacturing technological process of the screen production in order to make screens which are capable of reproducing more colors. Some screen profiles with enhanced color reproduction have been made for the most popular standards of the white color.

1. Introduction
The primary information display means in the modern computer technics are LCD (liquid crystal display) or LED (light emitting diode) screens [1, 2]. The color of each display pixel can be determined with the commanding codes of the three primary colors \(RG\text{B} (R \rightarrow \text{Red}, G \rightarrow \text{Green}, B \rightarrow \text{Blue})\). The color coding model based on the \(RG\text{B}\) codes mixing determines [3, 4] in the \(XY\) colorimetric plane the gamut which boundaries can be approximated as a geometric form of a triangle. The color gamut triangle is located inside the spectral locus which characterizes all visible colors. So a display, which pixel control scheme is based on the three components \(RG\text{B}\) model cannot reproduce all colors and shades which can be seen with a human eye but some of them referring to colors and shades \((x, y)\) tristimulus coordinates of which are inside the color gamut triangle.

The tristimulus values of the color gamut triangle \((x_R, y_R), (x_G, y_G), (x_B, y_B)\) determine [5, 6] through the parameters \(X_r, X_g, X_b, Y_r, Y_g, Y_b, Z_r, Z_g, Z_b\) of the display profile — the display color reproduction mathematical model and the size of the color gamut triangle as well as its location in the \(XY\) plane can characterize the display ability to reproduce some particular colors and their shades. The display profile parameters can be determined with the liquid crystals or LED manufacturing technology and can be calculated [7-10] theoretically or evaluated according to the results of colorimetric measurements.

A display with the maximum possibly size \(S_{\text{max}}\) of the color gamut triangle inscribed into the spectral locus will have a profile with the best qualities of the color reproduction.

The display samples being manufactured today have the profiles which are different from the profile with the maximum size of the color gamut triangle (a normal display color gamut triangle size is approximately 30-40\% from the maximum profile size of the color gamut triangle) so that why it is an actual task to find out a display profile with the maximum size \(S_{\text{max}}\) of the color gamut triangle inscribed in the spectral locus.
The location of the color gamut triangle in the spectral plane

After the solution of [6] the task to interpolate the spectral lines of the gamut we have a set of tristimulus values points which connection of which gives a closed curve in the tristimulus values plane. The extreme points of the spectral tristimulus values line correspond to the tristimulus values of the wave length λ[0]=380 nm and λ[N-1]=780 nm are connected with a straight line — the line of purple colors.

To determine the tristimulus values of the color gamut triangle with maximum size inscribed into the spectral locus an algorithm can be used which include step-by-step interpolation accuracy improvement of the locus form and rechecking of the obtained values of the color gamut triangle tristimulus values. It saves some machine time of the calculations and also the algorithm permits to evaluate the accuracy influence of the used interpolation method based on the Besie curves upon the received values of the color gamut triangle tristimulus values.

The value search algorithm of the color gamut triangle tristimulus values supposes that all the points inside the color gamut triangle and near its boundaries are in the spectral locus visible colors. The first step is to determine the triangle with the maximum size of the color gamut based on the initial data where the table value of the wave step is Δλ=5 nm. So the initial approximation is formed. The obtained triangle coordinates of the spectral colors line correspond to the points with the coordinates (xR,yR), (xG,yG), (xB,yB) and wave lengths λR, λG, λB. Then the algorithm redetermines the triangle location after the interpolation of the spectral locus shape with a smaller step Δλ=1 nm in the points received after the previous step or: λR±10Δλ, λG±10Δλ, λB±10Δλ.

The rechecked set of parameters λR, λG, λB applies further in the algorithm as a new approximation and it iterates until the step value is Δλ=0.0002 nm. The step value Δλ=0.0002 nm accepted in the algorithm as the minimum permitted after which the size increment of the color gamut triangle can be calculated with the formula:

$$S_{max} = \sqrt{p(p-l_{BG})(p-l_{BR})(p-l_{GR})},$$

where

$$p = \frac{l_{BG}+l_{BR}+l_{GR}}{2}, \quad l_{BG} = \sqrt{(x_B-x_G)^2+(y_B-y_G)^2},$$

$$l_{BR} = \sqrt{(x_B-x_R)^2+(y_B-y_R)^2}, \quad l_{GR} = \sqrt{(x_G-x_R)^2+(y_G-y_R)^2},$$

which becomes the same with the given results accuracy of the calculations in the used model medium Mathcad 15.0 and it is 10⁻¹⁵.

The triangle coordinates calculation for CIE 1931 and CIE 1964

The color gamut triangle obtained after modelling which has points which coordinates are out of the spectral locus shape can be rejected in the algorithm. Such color gamut triangle may exist because of non-linearity of the spectral colors lines in the wave length range 380 nm – 410 nm where a boundary of the color gamut triangle which connect the coordinates (xR,yR) and (xB,yB) partially will be out of the visible colors range. Evaluations [5, 6] of the display profile coefficients which corresponds the colorimetric standards accepted by CIE (Commission Internationale de l'Eclairage — International Commission on Illumination) D-75, D-65, D-55, D-50 for the white color points of the CIE 1931 and for the CIE 1964 given in the table 1 and table 2 respectively.

Any triangle made with RGB codes mixing for a display with eight bits bi-value representation of the primary color each code includes $2^8 \cdot 2^8 \cdot 2^8 = 2^{24}$ tristimulus coordinates of the colors and shades reproduced on the screen. The density of the color gamut triangle of the tristimulus coordinates is higher when the triangle size is less or when the color gamut triangle is reduced the distance between neighbor tristimulus values is reduced.

Practical calculations of the color gamut triangle size for several mass-produced displays and a display with the maximum color gamut triangle size are given in the figure 1 (based on the CIE 1931 example).
Table 1. The profile display coefficients with the color gamut triangle maximum size for the CIE 1931.

| White color standard | Display profile coefficient | Direct transformation: RGB→XYZ | Reverse transformation: XYZ→RGB |
|----------------------|----------------------------|----------------------------------|----------------------------------|
| D-50                 | [0.764 0.052 0.148]        | [1.33 -0.06 -0.27]               |                                  |
|                      | [0.273 0.72 0.007]         | [-0.51 1.41 0.09]                |                                  |
|                      | [0 0.096 0.729]            | [0.07 -0.19 1.36]                |                                  |
| D-55                 | [0.736 0.053 0.168]        | [1.38 -0.06 -0.28]               |                                  |
|                      | [0.263 0.729 0.008]        | [-0.5 1.4 0.09]                  |                                  |
|                      | [0 0.097 0.82]             | [0.06 -0.16 1.2]                 |                                  |
| D-65                 | [0.695 0.054 0.20]         | [1.37 -0.06 -0.29]               |                                  |
|                      | [0.24 0.74 0.02]           | [-0.5 1.37 0.09]                 |                                  |
|                      | [0 0.099 0.99]             | [0.05 -0.14 1.2]                 |                                  |
| D-75                 | [0.705 0.052 0.148]        | [1.37 -0.06 -0.29]               |                                  |
|                      | [0.30 0.68 0.02]           | [-0.6 1.51 0.08]                 |                                  |
|                      | [0 0.106 0.7]              | [0.09 -0.23 1.4]                 |                                  |

Table 2. The profile display coefficients with the color gamut triangle maximum size for the CIE 1964.

| White color standard | Display profile coefficient | Direct transformation: RGB→XYZ | Reverse transformation: XYZ→RGB |
|----------------------|----------------------------|----------------------------------|----------------------------------|
| D-50                 | [0.77 0.05 0.14]            | [1.3 -0.06 -0.26]                |                                  |
|                      | [0.30 0.68 0.02]            | [-0.6 1.51 0.08]                 |                                  |
|                      | [0 0.106 0.7]               | [0.09 -0.23 1.4]                 |                                  |
| D-55                 | [0.75 0.05 0.16]            | [1.37 -0.06 -0.27]               |                                  |
|                      | [0.29 0.69 0.02]            | [-0.59 1.49 0.08]                |                                  |
|                      | [0 0.11 0.8]                | [0.08 -0.2 1.24]                 |                                  |
| D-65                 | [0.70 0.05 0.19]            | [1.45 -0.07 -0.29]               |                                  |
|                      | [0.28 0.7 0.02]             | [-0.58 1.47 0.08]                |                                  |
|                      | [0 0.11 0.1]                | [0.07 -0.17 1.03]                |                                  |
| D-75                 | [0.67 0.05 0.22]            | [1.52 -0.07 -0.3]                |                                  |
|                      | [0.26 0.71 0.03]            | [-0.57 1.45 0.08]                |                                  |
|                      | [0 0.11 1.1]                | [0.06 -0.15 0.91]                |                                  |
Figure 1. Results of the tristimulus value calculations of the color gamut triangle for the CIE 1931.

The direct (reverse) transformation in table 1 and table 2 is performed according to the rules:

\[
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
= \begin{bmatrix}
X_r & X_g & X_b \\
Y_r & Y_g & Y_b \\
Z_r & Z_g & Z_b
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
= \begin{bmatrix}
X_r & Y_r & Z_r \\
X_g & Y_g & Z_g \\
X_b & Y_b & Z_b
\end{bmatrix}
^{-1}
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]

So the maximum size of the inscribed in the color locus of the color gamut triangle for the CIE 1931 is several times higher than the color gamut triangle size which are being produced today display models with the color reproduction scheme of three colors.

4. Conclusion

After the solution of the task to evaluate the tristimulus value of the color gamut triangle of the maximum size inscribed in the spectral locus some numeric values of the display profile were received which correspond the colorimetric standards of the CIE 1931 and the CIE 1964 to program the white color point D-75, D-65, D-55, D-50.

Having analyzed some technical documentation for displays of several manufacturers we can say that their color gamut triangle size is almost the same in the range of 0.06-0.12 points^2 which is not higher than 50% of the color gamut triangle of the maximum size. As a result the primary task for the
display of the tree component pixel control scheme developers is to create a technology of display manufacturing which may give the color reproduction with the color gamut triangle maximum size.

References
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