Gray Tracking Correction for TFT-Lcds

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Abstract

The consistency of the white point with the input gray level is referred in the world of display technology as gray tracking.[1] Gray tracking is an issue for Twisted Nematic (TN) TFT-LCD screens which typically show a bluish shift of the white point when the gray level decreases. This paper discusses some causes of the colorcast in TN displays and proposes a method for correcting it by using the existing video card look-up tables (VLUT) in the graphic controller or in the panel itself. The correction process performs the gamma correction and the gray tracking correction simultaneously. The gray tracking correction uses the luminance and the chrominance information of the R, G, B channels. For a single VLUT entry, for the corresponding output value in one channel (G for example), the method computes the output values for the other two channels (R and B respectively) such that, the resulted gray has the minimum chromatic difference to the desired white point of the display. The method proves to remove the colorcast in the TN TFT-LCD screens. The method is general and can be applied to any display technology.

Introduction

The consistency of the white point with the input gray level is referred in the world of display technology as gray tracking.[1] Gray tracking is an issue for gamma correction in TN TFT-LCD displays. In those displays, when performing gamma correction, the screen may end up having a colorcast. Some of the color cast is due to the native white point of the display, but even after the correction of the white point to a target white point, the display may still maintain a color cast that is more visible in the middle tones and dark tones. The colorcast may vary with the gray level and in general becomes more bluish as the gray gets darker. In addition to this behavior, if the panel has asymmetric luminance response on R, G, B channels, the fine gray transitions of consecutive gray levels may be perceived as having a colorcast of multiple hues. For example, for a panel with 8 bits/pixel, a gray variation of 20 consecutive levels may induce a greenish, bluish or reddish (or other combinations of these) colorcast. This is very disturbing behavior of the display, for computer generated images like GUI elements using grays, or for black and white images that may show color banding for fine gray transitions.

The gray tracking can be measured as the chromatic difference between the chromaticity of the desired white point and the chromaticity of the gray measured for equal input values of RGB signals. Another way to quantify the gray tracking is through the use of the correlated color temperature of grays. It is interesting to note that for CRT devices, the gray tracking is very good due to the equal native transfer functions for all three RGB channels. For CRT displays, equal R, G, B values produce grays with the chromaticity very close to the one of the maximum white. It is important to note that the gray tracking is influenced by flare. Taking out the influence of the viewing flare by a method presented in Ref. 2 reveals for CRT an excellent gray tracking performance.

This paper describes a method to improve the gray tracking for TFT-LCD panels by using the existing VLUT of the display. No additional hardware circuitry or system changes are required. The method is based on finding for each input gray value the proper balance of red, green and blue output from the video card that will render the closest neutral color to the desired white point. The compensation is done per each individual gray level, and it ensures that across the entire input range, the rendered gray has the minimum chromatic variation from the desired white point. In particular, for each input value, the green output is determined according to the target gamma response of the panel and the red and the blue output values are chosen such that the gray results with the closest chromaticity coordinates to the desired white point. The desired white point can be for example the target white point or the device native white point.

In the next section some causes of the colorcast are discussed. The third section describes the method in detail and the last two sections discus the results and draw the conclusions.

Gray Tracking on TFT-LCDs

In addition to the influence of the native white point of the display and the influence of the viewing flare, gray tracking on TFT-LCD depends on several factors:

1. First, TFT-LCD technology determines essentially the consistency of the white point of the panel with the input gray level. For TN technology (the most popular one today), there is an inherent difference between the transfer functions of the R, G and B channels mainly due to their dependency on the wavelength. This is explained by the TN transmittance formula[1] $T = a.\ \Delta n.\ d / \lambda$, where λ is the wavelength, d is the cell gap, Δn is the optical anisotropy of the LC material and a is a constant.

2. Second, it can be observed that the chromaticity of the primaries varies in hue as a function of the input level. Figure 1 illustrates an example of such variation with the input level. The chromaticity variation of the primaries can be observed even after the flare compensation is performed (as suggested in Ref. 2). This variation reported earlier[3,4] may be explained by two interacting factors. First, the transmittance of the liquid crystal cell depends on the wavelength of the transmitted light and on the input level of the signal, as it is illustrated in figure 2.[5,6]

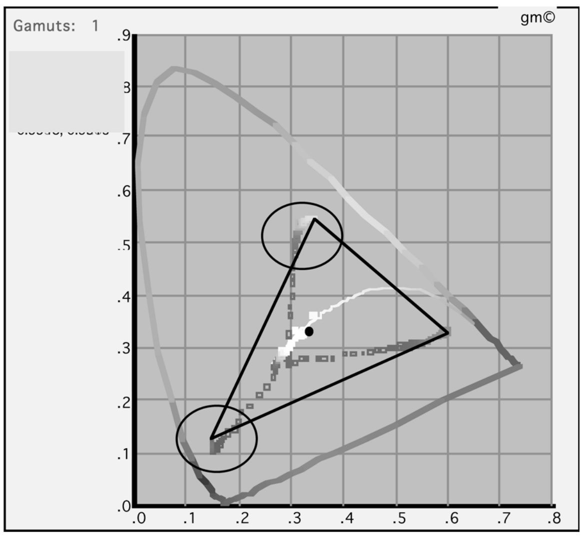


Figure 1. Hue variation of the primaries with the input level

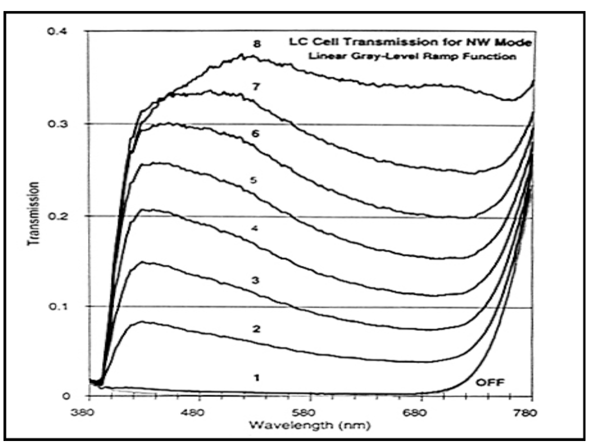


Figure 2. Voltage to luminance transfer function

Second, the power spectral distribution of the backlight has multiple spikes for each primary. As result, for blue for example, the attenuation of the spikes is different for different gray levels. In the example presented in figure 3, the blue level 255 has the cyan spikes less attenuated than the blue level 128. This conducts to a more cyanish blue for level 255 than for level 128. The cyanish spike (around 480 nm) is attenuated less compared with the blue spike (around 430 nm) in case of blue level 255 compared with the blue level 128 (as it is indicated by different ramps of the line connecting the two picks). As result, the blue for level 255 is more cyanish than the blue for level 128. Thus, the blue chromaticity varies from cyanish to bluish as the input level decreases from maximum value (255) to middle values (128). Similar behavior is recorded on green channel. This phenomenon is not so severe on red channel, because the backlight has a single spike in the red region of the spectrum and there is no input level dependent balance between two spikes to produce a chromaticity shift.

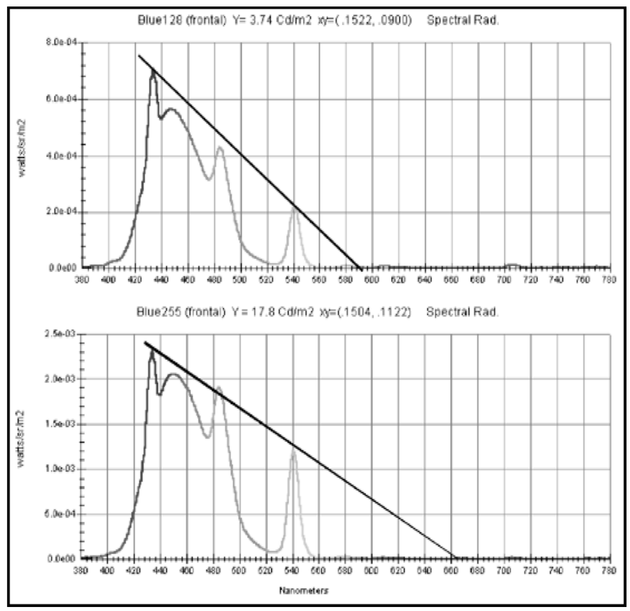


Figure 3. Migration of blue primary in hue due to less attenuation of the cyanish pick

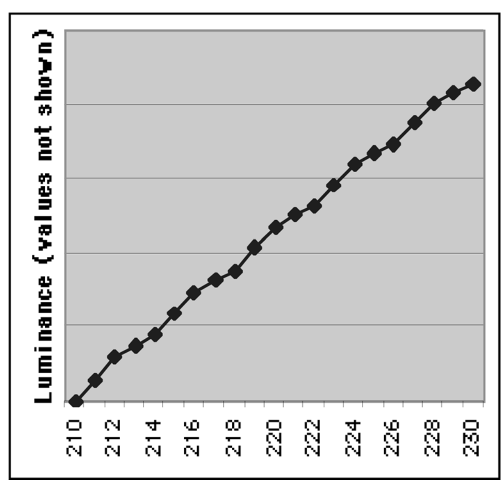


Figure 4.Example of non-uniform luminance variation due to the effect of time frame modulation.

3. Third, most of the 8-bits per pixels TFT-LCD screens in today's portable computers use 6 bit driven panels and the remaining levels (corresponding to the least significant 2 bits) are produced by time frame modulation. The gray levels produced by time frame modulation are not evenly distributed in luminance. The luminance step resulted from switching on the first frame is different than the luminance step from switching on the 2nd, 3rd, or 4th frame in sequence. The result is that gray levels created by the time frame modulation are not uniform. This is illustrated in figure 4. This behavior in conjunction with gamma correction of asymmetric R, G and B channels may conduct to color banding corresponding to the less significant bits. In other words, for time frame modulation panels, adjacent gray levels may show color banding.

All these issues can be addressed and corrected using the method described in the next section.

The Method

The idea of the proposed method is to find for each G value, the balance of R and B values such that the gray created by additive mixture of the resulted red, green and blue colors has the closest chromaticity coordinates to the desired white point. The desired white point can be chosen to be the native white point or the target white point chosen by the user. The green component is selected as reference because it has the highest contribution to the luminance of the display and thus, the red and blue adjustments induce the minimal change in panel's luminance transfer function (therefore the alteration of target gamma correction on red and blue in favor of gray tracking correction is less objectionable).

The proposed method uses the luminance and the chrominance information of the R, G, B channels. The luminance and chrominance native response of the panel on each R, G, and B channel is measured for each input level of the panel (including those created by time frame modulation, if present).

For a single VLUT entry, for the corresponding output value in one channel (G for example), the method computes the output values for the other two channels (R and B respectively) such that, the resulted gray has the minimum chromatic difference to the desired white point of the display.

As it can be seen, the green component is used as reference and the proposed method computes the correction tables for red and blue components to satisfy the gray tracking constraints.

If the green reference represents the panel native response, then the resulted R and B tables correct for gray tracking for the native response of the panel. These tables may be stored at the time of panel manufacturing in the TFT-LCD panel, if such option is available. This will result in a panel with high gray tracking performance response.[7]

If the G reference represents the correction table for a target gamma, then the resulted R and B tables include combined effect of both target gamma and gray tracking corrections.

In our implementation, a searching procedure is used to select from all combinations of red and blue values for a given green value, the one that minimizes the chromatic color difference to the desired gray. The algorithm can be described in pseudo code in the following steps:

1. Select and set the chromaticity of the desired white, ***W***, to which the panel is corrected
2. Set the correction table, **GLUT**[k], for G channel (the correction to a target gamma is done here)
3. For each input of the VLUT, k = 0 to max {

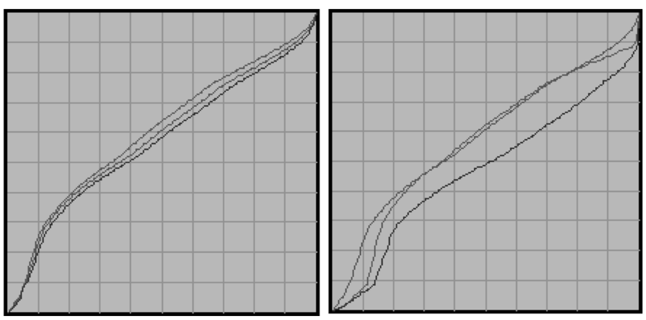
```
        g = GLUT[ k ]; ( G channel is not modified )
        Set ChromaticDifferenceLimit,, D, to a large value
        For r = 0 to max {
            For b = 0 to max {
                Compute C = AdditiveMixture( r+g+b )
                ChromaticDifference = C – W
                If( ChromaticDifference • D ) {
                    RLUT[ k ] = r , BLUT[ k ] = b
                    D = ChromaticDifference
                }
            }
        }
    }
```

It can be seen that the target gamma compensated panel with gray tracking correction may have slightly different target gamma response for red and blue channels than the gamma compensated panel based on individual R, G, B channels with the conventional approach. This is expected since R and B channel gamma correction is derived from G channel gamma correction and the gray tracking constraints, rather than from independent luminance response of R and B channels, respectively. But we have found that for most imaging applications the proposed gray tracking correction is the preferred correction to the one based on the conventional target gamma correction. The procedure can be repeated iteratively, for fine-tuning the global gamma correction if desired, but we found that for most application a single iteration gives acceptable results.

Results

The gamma correction for several TFT-LCD panels was computed and evaluated. It was found that the panels with corrected gray tracking render the images more naturally than the one using independent gamma correction for the same target gamma. Especially the grays and the warm colors (including the flesh tones) benefit from this correction. The bluish cast over the images was removed and the naturalness of the images was restored. As it can be observed in the example shown in figure 5, the gray tracking with gamma correction may differ significantly from a conventional target gamma correction.

It was found that the gray tracking compensation was effective in removing even the color banding for adjacent gray levels (caused by the time frame modulation). This was possible because the gray tracking correction was done per each individual gray level, and independent on the color correction of adjacent level. The only constraint was on the monotony of each of the resulted R, G, B correction curves. The compensation can accommodate the color shift from various causes (time modulation, flare, dependency on the wavelength, or other effects). This makes the method applicable to other display technologies, not limited to TFT-LCD. However, due to the limited number of bits for coding the VLUT output values, not all color banding can be removed and in some cases of high brightness displays some color banding may still be visible in the dark grays. To completely correct for these artifacts, the VLUT output should use more than 8 bits/channel (the number of input entries may remain unchanged).



(a) *(b)*

Figure 5. Example of gamma correction tables without (a) and with gray tracking compensation (b) for a TN TFT-LCD panel

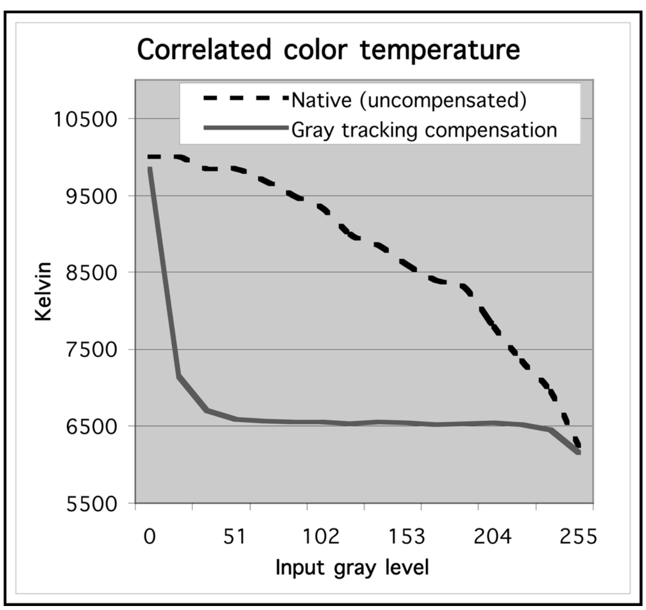


Figure 6. The effect of gray tracking compensation on the correlated color temperature of a sample TFT-LCD panel.

An analysis on the optimum color difference formula to be used in the algorithm has not been carried out. It is believed that the recently proposed color difference formula[8] should be the most appropriate one for this application. For the first approximation however, the authors found that the color difference formula did not influence significantly the results of the method.

Figure 6 shows the gray tracking compensation effect on the correlated color temperature for the entire range of gray levels of a sample TN display. It can be seen that the correlated color temperature shift (about 2500K) for the middle grays is compensated to a stable 6500K+/- 100K.

Finally, it can be imagined that the same method of gray tracking correction can be applied to other display technologies, or for printing, provided if the subtractive mixing mechanism is used (or printer model, or raw measurements and interpolation) instead of the additive mixing mechanism used for display. Various developments of this method can be imagined.

Conclusion

A simple correction method for gray tracking was proposed. The method performs the gamma correction and the gray tracking correction using only the existent video card 1D LUT (VLUT) available in most display controller IC. The method was applied for gray tracking correction of TFT-LCD devices but it is general and it can be extended to various (additive or subtractive) color rendering devices.

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Biography

Dr. Gabriel Marcu is Senior Scientist in ColorSync group, at Apple Computer. His achievements are in color reproduction (device characterization and calibration for display and print, halftoning, gamut mapping, ICC profiling). Dr. Marcu has taught seminars and short courses on color topics for Shizuoka University, Japan, UC at Berkeley, EMI Europe in Cambridge, UK, and various IS&T, SPIE, SID conferences. He is co-chairman of the EI Color Imaging Conference: Color processing, Color Hardcopy, and Applications and Program Co-Chair for the 10th Color Imaging Conference in Scottsdale, AZ.