Constructing an ICC Display profile: How It Really Works

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Abstract

Finding a standardized way to communicate between different digital devices in terms of colors was the main interest for many graphic communications industries. Color Management was the solution system and ICC profile was the tool. By capturing the device's color behavior in a standardize format, color transformation could be accurately achieved among different media. However, this accuracy depends on many factors. For example finding an accurate mathematical model that accurately interprets a device color space (RGB or CMYK) into a standard device-independent space (or Profile connection space-PCS) so it can be understandable by another color device. Other factors might be related to the constructions of an ICC profile, which could influence the accuracy and performance of that important file.

Generally, monitors have an important role in the graphic communication cycle. Taking this fact, this research focused on revealing all the details behind constructing a plausible display profile by using different mathematical models (Matrix and Look-up table models) to build an ICC profile for two different LCD monitors that are connected to one computer. A customized C++ code was assembled based on an open source library "Little cms" written by Marti Maria. This code was used as our ICC profile editor that can read and write different components of ICC profiles. Other display profiles were constructed using I1profiler software for each monitor for comparison purposes. Different evaluation tests that involve different software from Adobe Photoshop, Digital Color Meter and X-Rite MeasureTool, were employed to examine the accuracy of our constructed profiles and promising results were achieved.

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Introduction

CRT (Cathode Ray Tube) and LCD (Liquid Crystal Display) are two widespread types of display technologies. E-papers (Electronic Papers), LED (Light-Emitting Diode display) and OLED (Organic Light-Emitting Diode display) are some new developments of display technologies. LCDs have more advantages than CRT in terms of stability, brightness and sharpness, besides their high resolution, which make them more acceptable as display devices (Bala, 2003).

Generally, display devices are used not only for displaying purposes, but also they are playing an important role at different digital applications from graphic design to prepress Soft Proofing (Chovancova, 2003, Chovancova-Lovell et. al., 2007), where a client can preview the final product on the screen before the actual printing. Therefore, monitors are required to have good color reproduction, which reflects an accurate device characterization.

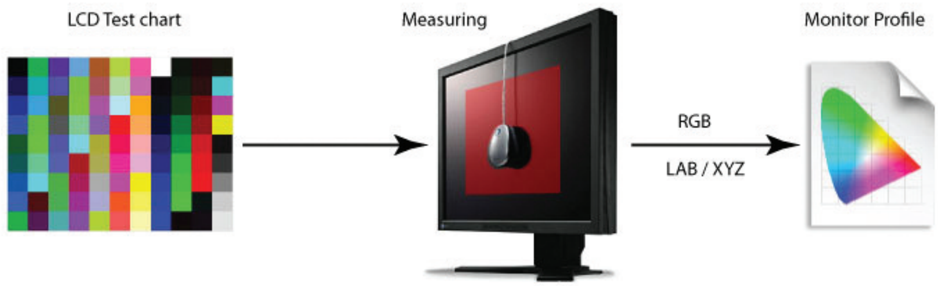


Figure 1: *Monitor characterization overall schema*

Figure 1 demonstrates the overall process of characterizing an LCD monitor. Generally, there are two test charts that are available for the characterization process: CRT and LCD test charts. Each chart consists of a set number of color patches that covers the monitor gamut. A measuring device is usually employed to measure each color patch while it's flashed on the monitor. The measurement data consist of the RGB / LAB or XYZ pairs for each color patch. Profiling software will then use these data to form both a forward (RGB to XYZ/LAB) and inverse (XYZ/LAB to RGB) color transformation model and store it in a suitable monitor profile. (Sharma, 2004)

The purpose of this experiment is to provide a plausible universal characterization model that can be use to describe different LCD monitors and minimize any measurement noise. This experiment also gives a better understanding of the fundamentals behind constructing a monitor ICC profile.

Consistent color appearance of any image across media starts from consistent device characterization model. This study provides better understanding of the fundamentals behind the process of constructing scanner ICC profiles. In addition, we propose an enmeshed scanner characterization model, which minimizes the noise from measuring processes and produces a smooth transformation.

Fitting Model Fundamentals

In this study both monitors will be characterized based on a LUT (Look Up Table) model, where its entries will be populated through an empirical approach. This approach utilizes a regression model to estimate it coefficients. Two different regression models will be used in this study: the Least-square linear fitting model (for scanner and monitor) and the nonlinear polynomial model (for all tested devices).

Least-Square Fitting Model

Let P contain n measurement elements which correspond to X, Y or Z and Q be an *mxn* matrix that holds the number of terms where C will hold the best-fit corresponding of m coefficients. The linear function can be expressed as:

$$\mathbf{P = QC + E} \tag{1}$$

Where *E* is the residual error that has n elements. We find $\hat{C}$ that minimizes E such that

$$\hat{\mathbf{C}} = (\mathbf{Q}^{\mathbf{T}}\,\mathbf{Q})^{-1}\,(\mathbf{Q}^{\mathbf{T}}\,\mathbf{P}) \tag{2}$$

Where Q^T is the matrix transpose. Then $\hat{C}$ will be denoted as the Least-square solution. (Green, 2002) (Kang, 2006)

Polynomial Fitting Model

For some digital devices, such as a CRT, the use of linear Least-squares model to characterize the device would be sufficient. Other devices require a higher order model such as a polynomial. The order of this model can increased up to *n-1* order, where n is the number of variables. In addition, the same form of this model can be used for both forward and inverse color transformation. (Bala, 2003)

A 2nd-order polynomial model was selected for this study, with a total of 9 terms. A forward transformation model from RGB to XYZ can be expressed as follow: (Kang, 2006)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} c_{1,1} & c_{1,2} & c_{1,3} & c_{1,4} & c_{1,5} & c_{1,6} & c_{1,7} & c_{1,8} & c_{1,9} \\ c_{2,1} & c_{2,2} & c_{2,3} & c_{2,4} & c_{2,5} & c_{2,6} & c_{2,7} & c_{2,8} & c_{2,9} \\ c_{3,1} & c_{3,2} & c_{3,3} & c_{3,4} & c_{3,5} & c_{3,6} & c_{3,7} & c_{3,8} & c_{3,9} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \\ RG \\ RB \\ GB \\ R^2 \\ G^2 \\ B^2 \end{bmatrix} \tag{3}$$

Transformation Requirements

Let *M* be the *3x3* matrix that holds either the coefficients of the Least-square model or the linear coefficients of the polynomial model. For a well-behaved forward transformation, *M* should satisfy both the *non-singularity* and a constant sign *Jacobian determinant* conditions. A non-singular matrix is an invertible matrix that is also diagonally dominant (Wikipedia, 2011a). This condition is very important for both monitor and printer devices to insure the forward and inverse transformation between different color spaces.

For the Jacobian determinant's sign, a positive sign indicates a linear transformation from RGB to XYZ. While for CMY devices the nonlinear transformation from RGB to CMY enforces a negative Jacobian sign. Overall, a constant sign must be maintained through all transformation points, which reflect stable transformation performance. In addition, a non-zero Jacobian determinant value indicates that the transformation function is *continuously differentiable* and thus it is *invertible* (Wikipedia, 2011b).

Notes Related To Constructing ICC Profiles

ICC profiles consist of optional and required tags. Among all profile types four tags are common and required as well: Profile Description tag (desc), Media Whitepoint tag (wtpt), Copyright tag (cprt) and Chromatic Adaptation tag (chad). The Media Whitepoint tag consists of the tristimulus value of the media whitepoint values as measured from the reference target. The chromatic adaptation tag contain the chromatically adaption matrix that is used when the reference illuminant is not a D50. (Green, 2010)

For monitor device the test chart measurements were recorded under the native illuminant that is different than D50. Therefore, all the measurements required to be chromatically adapted to D50 before converting them to relative colorimetric. In addition, a D50 value should be saved in the Media whitepoint tag of the monitor ICC profile despite whatever the actual measure whitepoint. (Green, 2010)

Experimental Design

This paper is an extension of our previous experiment of studying the physical behavior of two different LCD monitors that are connected to the same hardware (El Asaleh *et. al.*, 2010). Therefore, the same set of hardware was used:

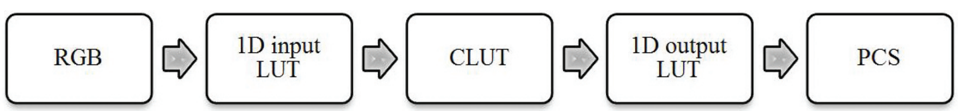
A dual quad tower Mac Pro with two LCD monitors was used to assist this experiment with the following specifications:

Monitors	24" Apple Cinema Display, 1920x1200, LED backlight 20" Acer, 1680x1050, Fluorescent backlight
Video Card	ATI Radeon HD 4870
Operating systems	MacOS 10.5 and Windows 7

Table 1: *Configuration of computer system for monitor profiles.*

Microsoft visual studio 2008 and VC++ were used to design and customize our profile editor code. This new code was designed with assistance of LittleCMS 2.2 (LCMS) library, which is a compilation of an open source program (designed by Marti Maria) (lcms, 2010) that can be used to construct and edit ICC profiles and it fully supports the newest ICC specifications (ICC, 2004).

Based on the generated gamma value from our previous work (El Asaleh *et. al.*, 2010), diverse display profile types (Matrix and LUT-based) were constructed using our profile editor (these will be denoted as lcms profiles). Two different device models were used to characterize our monitors the linear Least-square model and the nonlinear 2nd degree polynomial model, which was generated using Minitab for the RGB to XYZ transformation. Based on these models, a 3D LUT with 33 gird points was assembled and stored inside the AtoB Tags as a part of generating a LUT-based display profile. The selected combination of the AtoB tag elements that is used with the monitor profile is:



In addition, other LUT-based profiles were built for each monitor (ACER and Apple) using new profiling software called "X-rite i1 Profiler" and we used that for comparison purpose.

Monitor Model

The previous generate gamma values for Acer display was 2.2 and for Apple display was 2.1. Using these values LUT-based native whitepoint profiles were constructed on different platforms (Mac and Windows) using ProfileMaker 5.0.9 software and their measurement data were saved. Both measurement data for Mac and Windows were normalized to Y=100 and then averaged in Microsoft Excel to generate a general reference file for each display. These general reference files will be our training data for each monitor.

The selected fitting models for this paper were the Least-square (LS) linear model and the 2nd degree polynomial model for nonlinear transformation.

For monitor devices, the general form of a forward linear transformation from RGB to XYZ is:

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} X_{R,max} & X_{G,max} & X_{B,max} \\ Y_{R,max} & Y_{G,max} & Y_{B,max} \\ Z_{R,max} & Z_{G,max} & Z_{B,max} \end{bmatrix} \begin{bmatrix} (R/255)^{\gamma} \\ (G/255)^{\gamma} \\ (B/255)^{\gamma} \end{bmatrix} \quad (4)$$

where γ is the display "gamma" value. The entries of the local transformation matrix would be obtained from the measured RGB primaries from the training data.

Based on the general form of (4), the input values (RGB color values) should be normalized by dividing them by the maximum color intensity, which is 255. This indicates that the output values from this matrix are normalized too. To obtain that, XYZ values of training data should be divided by the Y value of the whitepoint to give X', Y' and Z'.

In addition, the gamma values for Acer and Apple monitors are 2.2 and 2.1 respectively, which indicates that the color transformation wouldn't be linear, unless the input values were raised to the gamma power. The general LS fitting form that were used for both displays is expressed as bellow:

$$X' = K_X + a_{1,1}R' + a_{1,2}G' + a_{1,3}B'$$

$$Y' = K_Y + a_{2,1}R' + a_{2,2}G' + a_{2,3}B'$$

$$Z' = K_Z + a_{3,1}R' + a_{3,2}G' + a_{3,3}B' \quad (5)$$

The intercept values *K* represent the measured black point, which is also denoting as the black-level flare. The intention is to use the intercept value from the Minitab software but these values were negative and therefore the measured black point was used instead. The occurrence of this value was due to the physical properties of the monitor backlight (Day *et. al.*, 2004). The effect of this flare was discussed in many researches (Fairchild *et. al.*, 1998, Day *et. al.*, 2004, Gibson *et. al.*, 2000), where the common intention was to remove it from the measurement data before generating any models, which was the same intention in this experiment. However, we re-plug the black-level flare back to our model to maintain the captured native behavior of our characterized device.

Equations (5-7) were used to construct the Matrix-based profiles and a linear LS LUT-based profile for each monitor using our profile editors. In addition, the linear RGB and XYZ values from the training data were used with Minitab to build the forward regression nonlinear polynomial model for each monitor. All these models were used to construct the non-Linear LUT-based profiles using our profile editor for each monitor.

To evaluate both LS fitting and the Polynomial fitting behavior, Jacobian determinant and RMSE tests was employed and the results are displayed in Table (2). The determinant value for the polynomial fit model was calculated from the average determinant values of all LUT entries inside the constructed lcms profile. While the RMSE error is the average computed error value for each X, Y and Z transformation functions.

The overall positive results for the determinant indicate well-behaved models for both monitors. In addition, despite the overall lower RMSE values, the Apple monitor models yielded the lowest RMSE errors that are less than 1 for both models.

	Acer		Apple cinema	
	LS	**Polynomial**	**LS**	**Polynomial**
Jacobian Determinant	1.977×10^5	2.198×10^5	2.193×10^5	2.166×10^5
RMSE	1.5817	1.1535	0.4583	0.2861

Table 2: *Calculated Determinant and RMSE for different monitors*

Moreover, the polynomial fit was slightly more accurate than the LS for both displays.

Simulation Results

Figure 2 represents an xy-chromaticity plot for LS LUT-based lcms profile, Polynomial LUT-based lcms profiles and i1 Profiler profiles for both Acer and Apple monitors. Overall, all plotted profiles whether for Acer or Apple monitors are so close that it is difficult to distinguish between them.

For the next comparison, only the polynomial fit profile was used since all lcms profiles are close. Figure 3 and 4 provides more detailed looks on the constructed profiles. Figure 3 shows the primary ramps in both polynomial fit lcms profile and i1 Profiler's profile for both Acer and Apple monitors. They clearly show the convergence of the primary ramps between the two profiles. However, for both Acer and Apple monitors the black point of the constructed polynomial's profile records the actual measured values, while for the i1 profiler the black records a zero value. This explains the difference in the black point plotting between the two profiles.

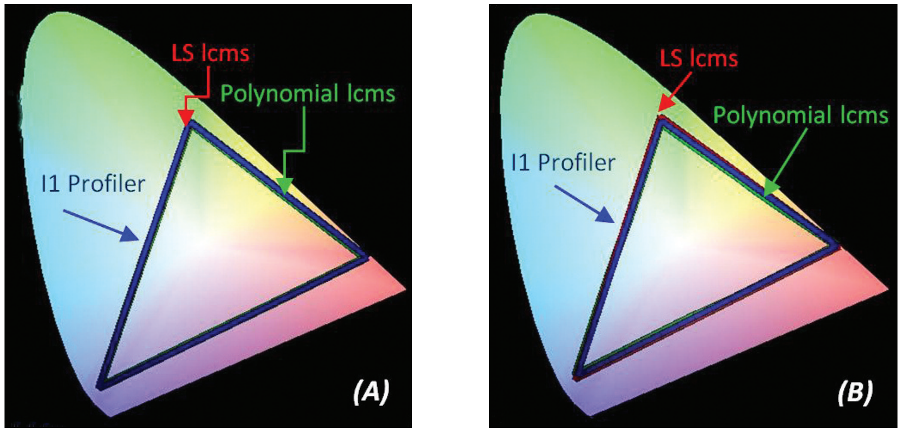


Figure 2: *The xy-chromaticity plots comparisons of different profile types for Apple (A) and Acer (B) monitors*

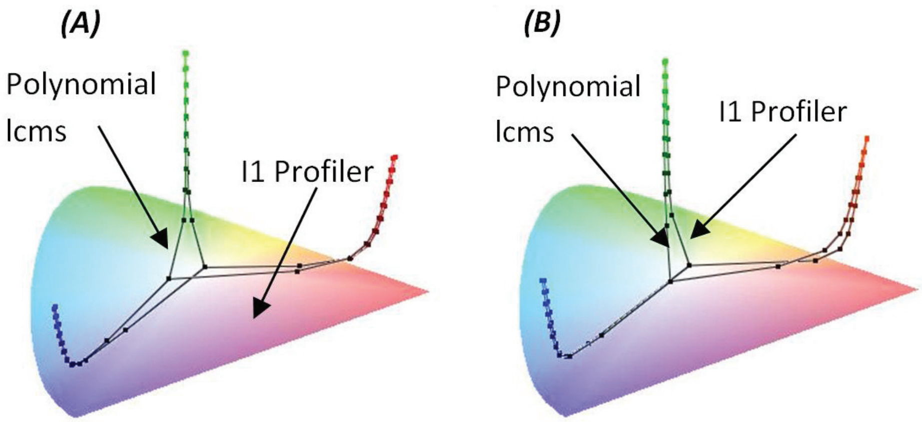


Figure 3: *The primary ramp comparisons of different profile types for Apple (A) and Acer (B) monitors*

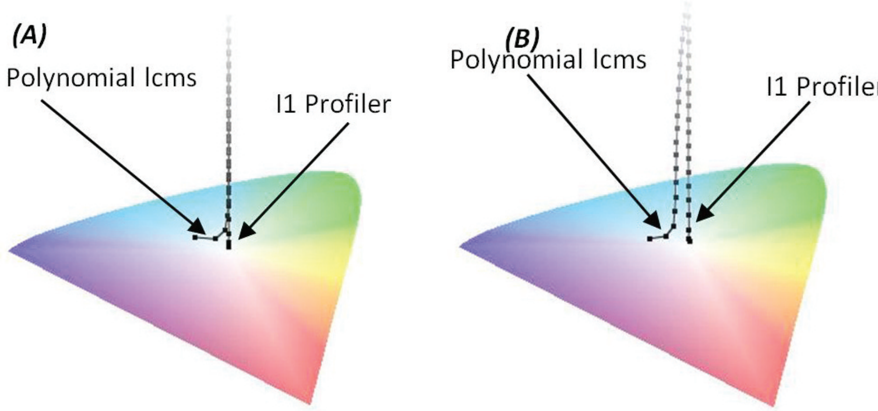


Figure 4: *The gray ramp comparisons of different profile types for Apple (A) and Acer (B) monitors*

The gray ramp comparison between the polynomial profile and the i1 profile for different monitors is shown in Figure 4. Despite the convergence between the two profiles toward the whitepoint value, it's obvious the significant difference between them toward the black point value.

For the evaluation procedure, a red, green, blue and white patches were constructed and measured. ΔE values were collected between the predicted and the measured data to evaluate the performance of the selected fitting models. The measured LAB values were collected from the info pallet in Adobe Photoshop CS5 and from DigitalColor Meter for each color patch. While the predicted values represent again the LUT entries inside the A2B tag for each profile. Since the Matrix-base lcms profile and the LS LUT-based profile use the same LS model, this comparison is generated using the LS lcms and Polynomial fit lcms LUT-based profiles.

As we stated previously about the chromaticity adaption of the LUT entries to D50 illuminant before they are stored inside the A2B tag in the monitor ICC profile, both Photoshop and DigitalColor meter reads the contents of that LUT. Thus, the

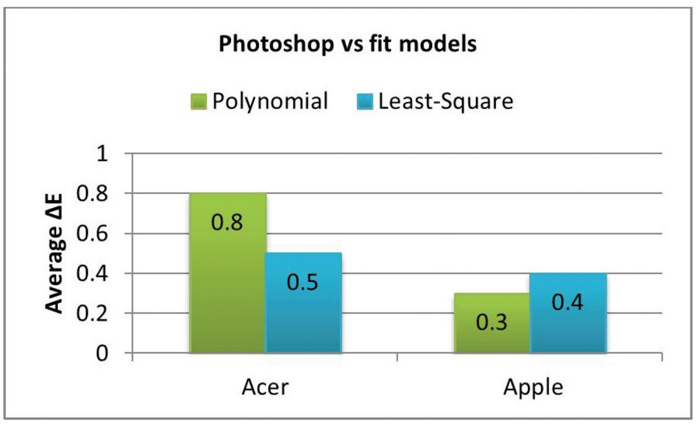


Figure 5: *average ΔE comparison between Photoshop data and different profiles and displays*

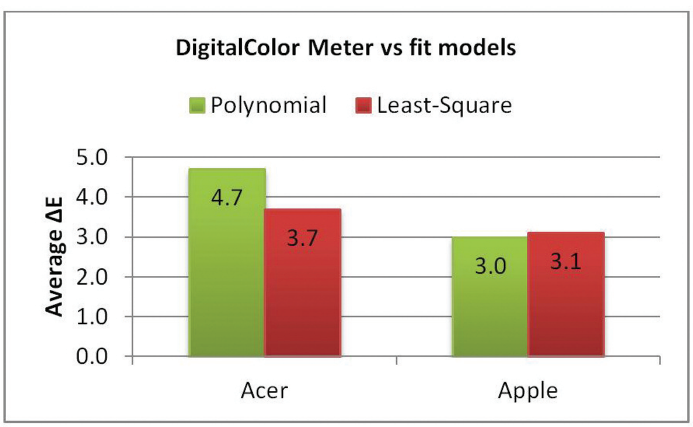


Figure 6: *Average ΔE comparison between DigitalColor Meter data and different profiles and displays*

aim of this evaluation is to test how well each software will interpret these contents. The resulting data are represented in Figures 5 and 6.

The overall average ΔE values were less than 5 which is acceptable however, its very noticeable that Photoshop has significantly lower values across fitting models and for both displays over the DigitalColor Meter values. Another way to look at this variation is to compare the same values between Photoshop and DigitalColor Meter for each display as Figure 7 shows. For this comparison, i1profiler was also employed.

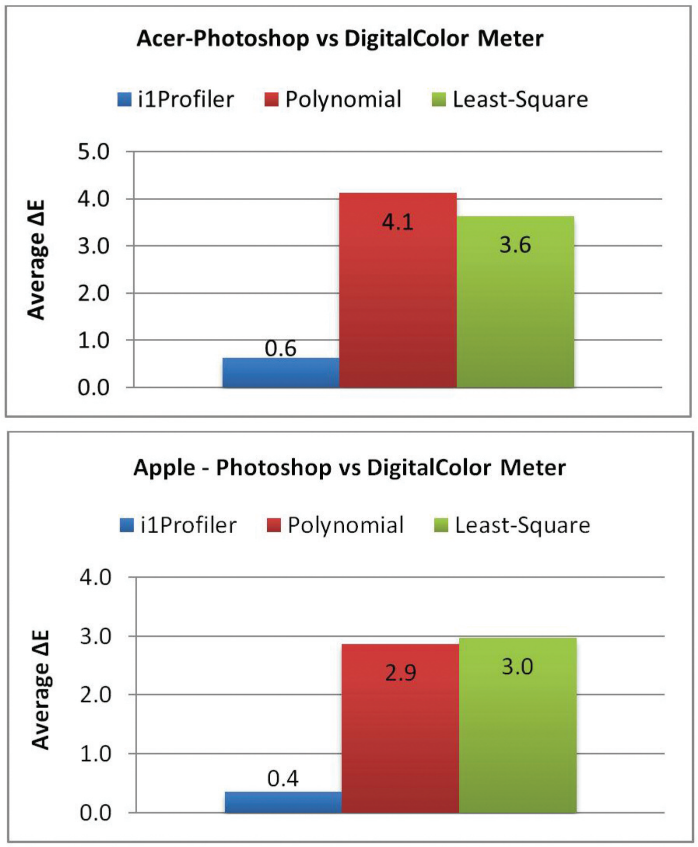


Figure 7: *Average ΔE comparison between Photoshop and DigitalColor Meter of different profiles for Acer (up) and Apple cinema (down) displays*

Overall i1Profiler has recorded the lowest ΔE values for both profiles, while values for Acer display were the highest. This variation could be due to the application itself and does not have anything with either the profile or the fitting model.

In addition, comparing the fitting models themselves, it can be seen that the polynomial model has a better performance with Apple display over the Least-square model as oppose with Acer display and both Photoshop and DigitalColor Meter had recorded the same behavior.

Future work

This research was focused on the forward transformation from RGB to PCS. However, the inverse transformation from PCS to RGB is also important for monitors and B2Ax tags are also required as part of LUT-based profiles. While this part was easy to conduct with the LS lcms profile by inverting the forward transformation matrix, for the nonlinear part it was quite complex. The goal is to find a better way to invert the proved accurate forward transformation model to retrieve the actual recorded device-dependent values (the RGB values). This will require more investigations and studies to evaluate the existent models and probably be able to develop an enhanced inverse model.

There are many types of displays that exist today. The challenge is to find a universal characterization model that accurately records the color behavior of these devices. Since the polynomial fitting model had proved its accuracy with LED displays, are we able to achieve the same results with others?

Conclusions

Different results prove the unstable behavior of the Acer monitor with Fluorescent backlight over the Apple cinema display with LED backlight.

Both LS and polynomial fits record similar performance for characterizing different monitors with different backlights. Results have shown that the polynomial fit was more consistent with the Apple display, while LS was more consistent with Acer display.

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