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Automated Color Calibration of Display Devices

Andrew Shulman

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Type of Report: MS Project Report

Automated Color Calibration of Display Devices

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1 Introduction

If you compare two identical images on two different monitors, they will likely appear different. Every display device is supposed to adhere to a particular set of standards regulating the color and intensity of the image it outputs. However, in practice, very few do. Color calibration is the practice of modifying the signal path such that the colors produced more closely match reference standards.

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2 Calibration Standards

Televisions adhere to the ITU Rec. 709 standard, whereas computer monitors follow IEC 61966-2-1:1999, commonly referred to as sRGB. These two standards define the primary colors (red, green, and blue) in the same locations. They differ only in the defined gamma. The seminal papers in mathematically measuring color were written in 1931 and define all fundamental constants and equations out to two decimal places. They also recommend using linear interpolation to increase the available data for certain summations. In order to obtain more accurate data, all equations and constants were re-derived as fractions, eliminating accuracy concerns in intermediate steps. First, all experimental data was converted to fractions. Then, cubic

splines were placed onto the data. The summations over linearly interpolated data were instead replaced with integrals over the splines. From there, D65, the defined white point for the two reference standards, was calculated. Using the white point, the location of various saturated colors was determined. Finally, the function used to determine the error between a measured color and a reference color, known as delta-E (or dE, for short), was re-derived using the more accurate white point.

3 Method of Adjustment

Windows has a two-dimensional look up table which transforms digital color values into the format which will be transmitted to the monitor or television. Each entry is indexed by the sub-channel (red, green, blue) and the sub-channel's intensity (0–255). The look up table is initially a linear function of increasing intensity. If it were attached to a display device with perfect color reproduction, this linear ramp would be correct. However, per-panel variances necessitate adjustment to each sub-channel.

For every level of intensity i , there is a corresponding shade of gray, defined by the RGB triple (i, i, i) . Each shade of gray is examined in order, from white to black, and the entries in the look up table which correspond to that shade of gray are adjusted.

When a sub-channel is adjusted at a given intensity, it affects the entire picture. While per-pixel or even per-region calibration would be desirable due to imperfections in screen backlighting technology, the approach used does not support this.

4 Program Structure

The calibration program is divided into two parts, a client portion and a server portion. The client consists of a meter capable of measuring color characteristics, typically a colorimeter or spectrophotometer; the PC whose look up table is being adjusted, and the monitor which the meter is measuring. The meter and the monitor were both connected to the client PC, and transmits all relevant data to the server.

The server performs all required calculations and is capable of supporting multiple simultaneous clients. It receives measurement data from the client and determines the necessary adjustment. All calculations were done with arbitrary precision arithmetic.

5 Adjustment Process

Initially, the client sets the screen to white, measures it, and sends the result to the server. The server determines which sub-channel is the darkest and holds that one constant during the entire calibration process. The reason for this is because of the linear ramp in the look up table. There is initially no room for upward adjustment of white in the look up table, so all adjustments must be downwards. Because of these, the brightest two sub-channels are the only ones that will be adjusted.

The client then measures the screen and sends the result to the server. The server calculates the dE of this measurement against the reference values for that shade of gray, selects the individual sub-channel with the largest error, and sends the sub-channel to be adjusted to the client. The client makes the adjustment, performs another measurement, and sends the result to the server. The server calculates the dE of this second measurement and compares it with the first. If the new dE is lower than the old one then the change improved the accuracy of that shade of gray. In this case, the program continues to adjust the shade of gray. If the new dE is not lower, then the change did not improve the shade of gray or made it worse. In this case, the change is reverted and server instructs the client to update

the screen to the next darkest shade of gray and begin calibrating from there.

This process uses many small changes to adjust the grayscale rather than a few large changes because it is difficult to predict the magnitude of result that a change will have. Displays have a highly non-linear response at different intensities, so what may be a small change for a lighter color may be a larger change for a darker color. Because of this, the program has to take many measurements for each shade of gray adjusted. Because each measurement takes 1 to 2 seconds, this forces a typical calibration to take approximately an hour.

6 Experimental Validation

To determine whether calibration makes a difference, three screens were set up with identical test images. However, some of these screens were calibrated and some were not, determined at random. Participants were asked whether they could perceive a difference in the screens. If so, they were asked which they thought were calibrated and which they thought were uncalibrated. If not, they were asked if they thought the screens were calibrated or uncalibrated. After each round, they were told which screens were calibrated and which were uncalibrated.

Testers were always able to tell when a setup contained both a calibrated and an uncalibrated screen. They were initially unable to determine which picture was calibrated or uncalibrated, especially when presented with multiple panels which were all calibrated or all uncalibrated. However, when given sufficient feedback about which screens were calibrated and which were uncalibrated, they were able to determine the calibration status of a screen, even when all screens were the same.

7 Conclusion

The experimental results show the difference between a calibrated and an uncalibrated screen is apparent to the naked eye, and users are sensitive to the difference once they are shown both.