Color Matching of Projection CRTs in a Multichannel Simulator Display

Celeste M. Howard and Steven J. Riedler
UDRI, Armstrong Laboratory, Mesa, Arizona

Abstract

Output functions of eight projection CRTs in a multi-channel flight simulator display could not be fit by the 3-parameter theoretical model proposed by Berns, Motta, and Gorzynski. However, the data collection procedure recommended with the model did increase the efficiency of setting up and characterizing these devices. Satisfactory color matching across channels could not be achieved by computation alone but required computation with iterative search.

Introduction

Berns, Motta, and Gorzynski[1] describe a method of CRT colorimetry which has improved the efficiency of device-independent color control in their laboratory. The method includes a theoretical model of CRT performance which has three parameters (gain, offset, and gamma). For estimation of these parameters, the authors recommend a data collection procedure which requires relatively few radiometric measurements.

When the report of this method appeared, Armstrong Laboratory was about to replace the CRTs in eight Barco DATA 600 projectors serving a multi-channel flight simulator display. The CRTs had been in service for more than three years, and they were showing uneven patterns of diminished output (particularly in regions which frequently displayed sky color). A great deal of time had previously been required in setting up these devices and making the colorimetric measurements necessary to ensure matched colors across the entire display. If the Berns, Motta and Gorzynski (BMG) model could be applied to *projection* CRTs as well as to CRT *monitors*, it might provide better information to guide the setup process, and it might also shorten the time required for both setup and measurements.

Procedure

To facilitate device-independent color rendering, Armstrong had previously developed a Computerized Colorimetry System (CCS) based on procedures developed by D. L. Post[2,3]. CCS is a PC-based program which communicates with a Photo Research PR703A-PC spectroradiometer and with the display controller. In its Measure mode, CCS sends the digital codes in its input file to the display controller, one at a time; directs the radiometer to complete a measurement of the display output; and records the resulting data in a characterization (CZN) file. In its Predict mode, CCS uses the device CZN data to compute a digital code that is expected to produce a requested color (described in XYZ space), sends this code to the display controller, obtains a radiometric measurement, compares the measurement with the requested color, and modifies its estimated digital code as necessary. The Predict mode of iterative search has been very effective in matching colors across the simulator display, and it has been equally useful in ensuring accurate color control of CRT displays for vision research.

To use the BMG model, additional modules were added to CCS, and the input file of digital codes for Measure mode was reduced from a set of 50 codes to a set of eight. The original set of 50 followed the general practice of measuring the output of all 3 primaries at zero voltage, of each primary alone at several voltage levels (the others remaining at zero), and of all 3 primaries together at maximum voltage. CCS measured 16 levels for each primary so that the shape of the function between any two successive measurements would be approximately linear, allowing the computations in Predict mode to use piecewise linear interpolation[2] for RGB ↔ XYZ transformations. This procedure required a little more than an hour for each projection CRT.

The new BMG code set displayed and measured the output of each primary alone at maximum voltage, the others remaining at zero; then it measured the output of all three primaries operating together at the same voltage for each of five levels. These five "white" levels were closely similar to those used by Berns, Motta, and Gorzynski (0.299, 0.483, 0.699, 0.850, and 1.000, where 1 represents maximum voltage). The procedure required about 8 minutes. The BMG set saves time in two ways: by requiring fewer measurements, and by restricting them to a luminance range above several cd/m^2. Eliminating low luminances from the measurement set could also improve accuracy; a radiometer is both slower and less accurate in making low luminance measurements.

CCS was expanded to include a new module for calculating the gain, offset, and gamma parameters from the BMG set of eight measurements. Accuracy of the module's nonlinear optimization routine was tested by comparing its results with those computed by SYSTAT, a software program used and recommended by Berns, Motta, and Gorzynski. Use of the BMG measurements with a Barco Calibrator monitor in the vision research laboratory produced output functions which closely matched the functions obtained from the longer set of 50 measurements, and the gain, offset, and gamma parameters of the Calibrator were very similar to those presented in the published article.

Previous study of the Barco DATA 600s had shown that the output functions of the green CRTs were almost linear in logarithmic coordinates and therefore likely to be fit reasonably well by a gamma function. However, output functions for the red and blue CRTs had definitely not been log linear. Could the outputs of the replacement CRTs be made more nearly linear during setup, by better adjustment of their drive controls and of the nested gain and offset controls? Tracking the effects of these adjustments would be faster with the BMG approach, and it seemed possible that changes in values of the three parameters would be informative in guiding the adjustments. Therefore, when the new CRTs had been installed, the setup procedure was monitored using the BMG code set, which was expanded to include 18 (instead of five) "white" levels to avoid missing any significant inflections in the functions. Output of each CRT was adjusted to make its function as nearly log linear as possible while keeping the maximum white output of the projector within the range previously achieved by this display (i.e., 70 to 90 cd/m^2).

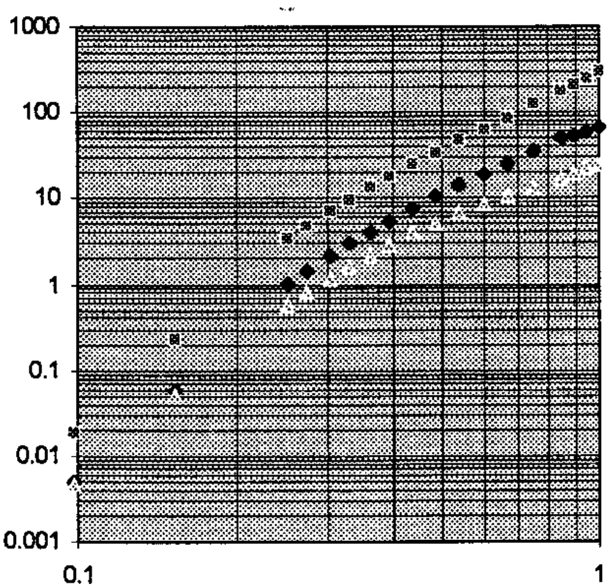

Figure 1. Output (in cd/m^2) of a Barco Data 800 CRT projector, plotted against input voltage (0.1 to 1 v) on logarithmic scales. This projector serves the small front window of Armstrong's new MiniDART display. Green CRT represented by squares, red by diamonds, and blue by triangles.

Results

With optimal adjustment of all three CRTs, it was still not possible to obtain log linear output functions. Figures 1 through 6 show output functions that were derived from these data by applying the method described in Berns et al.[1] to six "windows" from two different multichannel displays. Since they were not log linear, we did not attempt to characterize these functions in terns of gain, offset, and gamma parameters. Instead, we simply passed the functions to the CCS Predict utility, which applied the method of piecewise linear interpolation[2] to these functions exactly as if they had been generated by the usual more time-consuming method of measuring each primary independently at 18 voltage levels.

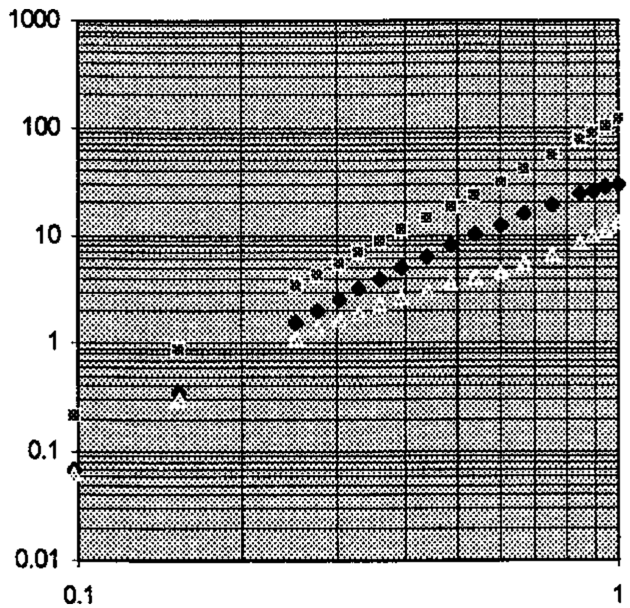

Figure 2. Output of a Barco Data 500 CRT projector serving the front window of the DART display. See Figure 1 for symbols.

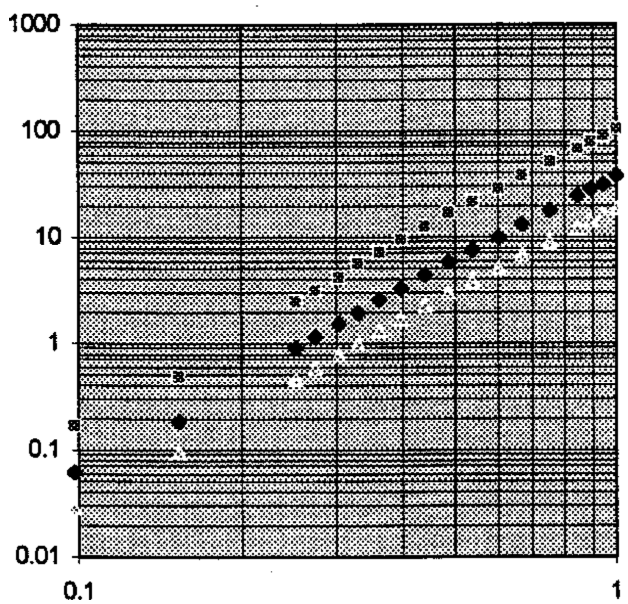

Figure 3. Output of Barco Data 600 CRT projector serving DART window 4 to the left of the cockpit. See Figure 1 for symbols.

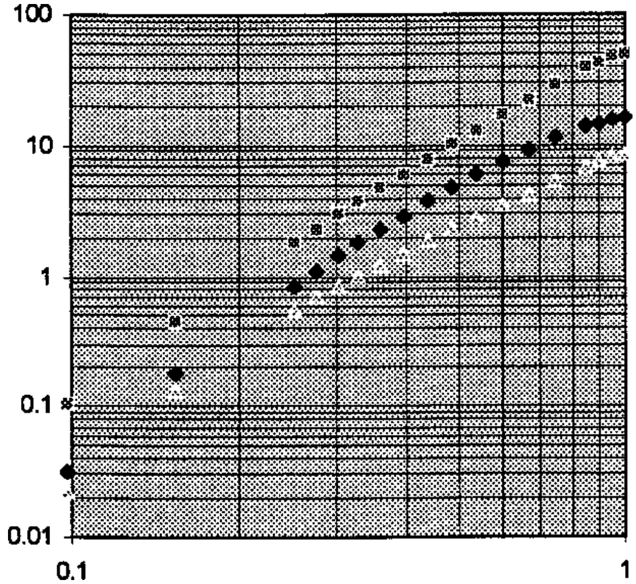

Figure 4. Output of a Barco Data 600 CRT projector serving DART window 5 to the right of the cockpit. See Figure 1 for symbols.

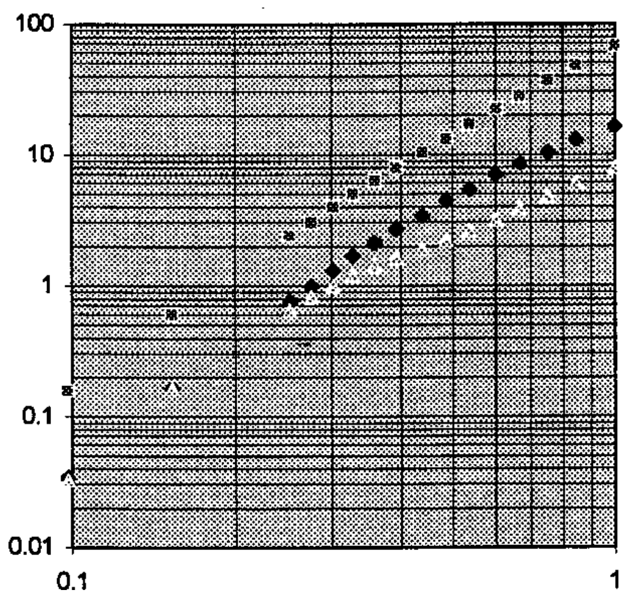

Figure 5. Output of Barco Data 600 CRT projector serving DART window 6 (left side toward rear).

During operation of the Predict utility on a list of 36 colors (described in terms of the desired u', v' and Y values), we observed *that the first digital code, calculated by matrix algebra from the CZN file, never produced an acceptable match to the desired color*. To meet our accuracy criterion (within a distance of .0025 around the desired u'v' position and within 3% of the desired Y value), two or more iterations were always required. Therefore, for one of the displays, we followed our previous procedure and took a full set of 50 measurements (including 16 voltage levels on each primary independently) to obtain a CZN file by direct measurement. We then compared the performance of Predict using this file with its performance using the CZN file derived by the Berns et al. method. The first digital codes calculated from the directly measured CZN file were no more accurate than those predicted from the derived CZN file, and convergence toward criterion was equally rapid with either file.

Therefore, users of computer-generated imagery in multichannel projection CRT displays should not expect to achieve device-independent color rendering by computation alone, even when they are able to make radiometric measurements characterizing each individual display. To match colors across the channels of such displays, characterization should be followed by iterative search for device-specific digital codes which will in fact produce the same design colors in each channel.

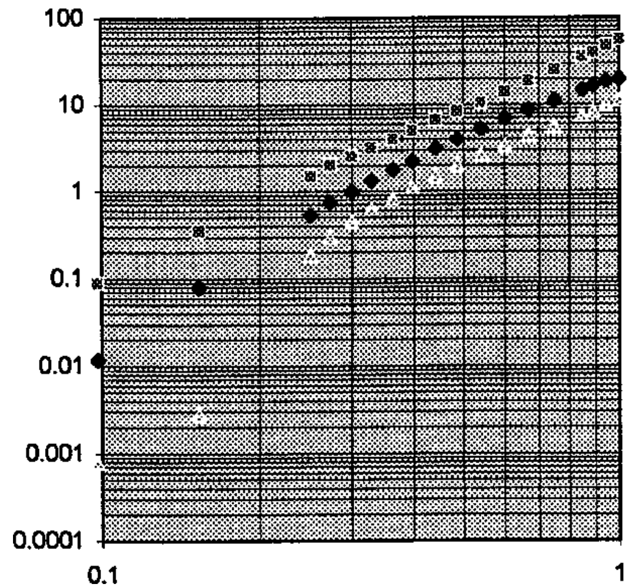

Figure 6. Output of a Barco 500 CRT projector serving DART window 9 (center rear). Note the sharp decline in blue luminance at low voltage levels.

Conclusion

Use of the BMG procedure has reduced the time required for characterizing each device from more than sixty minutes to less than ten minutes. The resulting data are then used to generate a characterization (CZN) file for use by CCS in the Predict mode, and Predict's iterative search for digital codes continues to operate by piecewise linear interpolation within the CZN file. Since the output functions are not, in fact, "gamma" functions, a computational solution to device-independent color matching is not feasible for projection CRTs, but a solution through iterative search is rapid and cost-effective.

References

1. R. S. Berns, R. J. Motta, and M. E. Gorzynski, "CRT colorimetry. Part I: Theory and practice," *Color Research & Application*, October 1993, **18**/5, pp. 299-314.
2. D. L. Post and C. S. Calhoun, "An evaluation of methods for producing desired colors on CRT monitors," *Color Research & Application*, 1989, **14**, pp. 172-186.
3. C. M. Howard, "An automated method of device-independent color rendering," *Proceedings of the 1990 IMAGE V Conference*, pp. 270-273.