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NIST Colorimetric Calibration Facility for Displays

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ABSTRACT

A facility has been developed at the National Institute of Standards and Technology (NIST) to calibrate color-measuring instruments for displays. The instruments will be calibrated for measurements of cathode-ray tube (CRT) and flat panel displays (FPD) using a reference spectroradiometer developed at NIST. To evaluate the overall performance of the system, several commercial instruments — spectroradiometers and tristimulus colorimeters — were calibrated for both a CRT and an FPD and compared for their measurement accuracy. Details of the NIST calibration facility and results of the comparison measurements are presented.

I. INTRODUCTION

Colorimeters and spectroradiometers are commonly used to measure the chromaticity (*x*, *y*) and luminance (*Y*) of displays, and useful protocols for color measurement using these instruments have been developed [1,2]. However, the instruments are normally calibrated against an incandescent standard lamp and errors for display colors (having very different spectra) tend to be much larger than manufacturers' specifications (often specified only for CIE Illuminant A). For example, inter-instrument variations for chromaticity measurements as large as 0.01 in *x*, *y* and 10 % in *Y* (corresponding to approximately 10 ΔE^{*}ab) have been observed for both commercial tristimulus colorimeters and diode-array spectroradiometers when measuring various colors of a display. Such measurement uncertainties would significantly degrade the quality control of the display products and the performance of any color management system.

To address the need for higher-accuracy measurements of displays, a project has been established at NIST to develop standards and calibration services for color-measuring instruments. While NIST has active programs in photometry [3], in flat panel display metrology [4] and in color and appearance measurements [5], these are the first services offered by NIST tailored to color-measuring instruments for displays.

II. INSTRUMENTATION

In this facility, instruments are calibrated directly against a reference spectroradiometer while measuring a CRT or a flat panel display. During a calibration, the reference instrument and the target instrument measure a particular display color, then the color is changed, and the measurements repeated. A reference matrix and a target matrix are thus compiled incorporating the chromaticity and luminance values of the various colors of the display. In the final calibration step, the target instrument values are transformed into corrected values that more closely approximate the reference values using a matrix correction technique — the Four-Color Method.

There are three important components of the calibration facility that we want to characterize and understand for an accurate assessment of the uncertainty of color measurements using a calibrated instrument: the operation of the reference instrument, the colorimetric characteristics of the display being measured, and the efficacy of the Four-Color Method in correcting the target instrument chromaticity and luminance values.

II.1. Reference Spectroradiometer

The reference spectroradiometer consists of imaging optics, a double-grating monochromator, and a photomultiplier tube for signal detection. The input optics include a reflex optic to image an area of the display onto an aperture, a relay lens to image the aperture onto the entrance slit of the monochromator, a depolarizer and order-sorting filters. The depolarizer reduces the polarization sensitivity of the instrument to less than 1 %, while the order-sorting filters eliminate higher-order diffraction effects. The monochromator center slit has been equipped with a stepper motor to control the slit width, and hence the slit scattering function, of the instrument during a scan. Operating characteristics, including wavelength errors, spectral slit scattering function, stray light, detector linearity, polarization sensitivity, and random noise have been measured; the results are summarized in Table 1. Further details of the characterization of the reference spectroradiometer are reported in Ref. [6]. Detailed simulations based on these measured operating characteristics of the instrument have demonstrated that it is capable of measuring a CRT or an FPD with an uncertainty of approximately 0.001 in *x*, *y* and 1 % in *Y* (~1 ΔE^{*}ab).

Table 1. Reference spectroradiometer characteristics.

Parameter	Value
Wavelength accuracy	± 0.1 nm
Slit scattering function	5 ± 0.1 nm, triangular
Stray light factor	< 2 x 10^{-6}
Polarization sensitivity	< 1 %
Random noise	< 0.2 % of the max. value

II.2. Colorimetry of Displays

The temporal stability, spatial nonuniformity, and angular variation in display colors all affect the overall accuracy of the calibration. For example, it is important that the display be stable over the measurement time. A typical measurement sequence takes approximately 15 minutes for each color. We measured the stability of chromaticity and luminance of a CRT and a liquid crystal display (LCD) — displays that we used for our calibrations — over the course of 7 hours for saturated red, green, blue, and white using the reference instrument. Because our reference instrument can measure displays with an uncertainty of approximately 0.001 in x, y and 1 % in luminance, we were looking for display variations on that order or less over a time frame of approximately 30 minutes. Results for the saturated red color of the CRT display are shown in Fig. 1. Over the course of 7 hours, the chromaticity values changed a total of approximately 0.001, while the luminance decreased by approximately 1.0 %. Similar results were obtained for saturated white, green, and blue colors, and for the LCD display. In each case, the display was found to be stable to within our measurement uncertainty over the 30-minute time frame.

II.3. Four-Color Method

Matrix techniques are known to improve the accuracy of tristimulus colorimeters for color display measurements [1,7], but often do not work as well as expected. These matrix methods are based on tristimulus values, and the accuracy of the luminance measurement affects the accuracy of the corrected chromaticity values. Flicker effects and other types of luminance noise are thought to be major contributing sources of error in the derivation of the correction matrix, leading to its reduced corrective ability. The Four-Color Method was therefore developed to eliminate luminance uncertainties from the derivation of the correction matrix. It utilizes chromaticity values only, eliminating the dependence of the efficacy of the technique on an accurate measurement of the luminance [8,9].

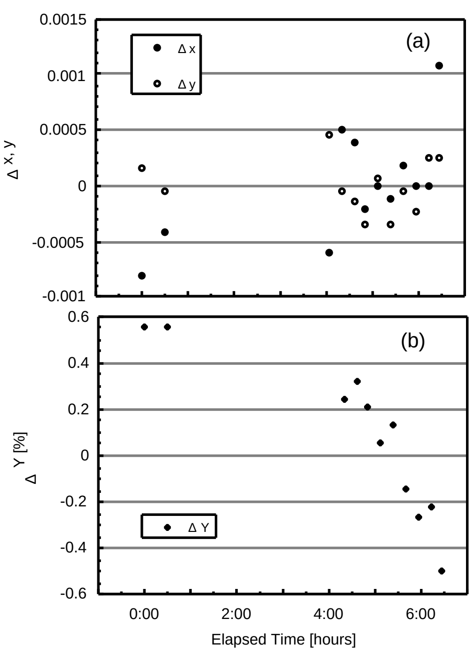

Fig. 1. Stability of (a) the chromaticity and (b) the luminance of a CRT display measured with the reference spectroradiometer.

For example, in Fig. 2, we show the results of a simulation conducted to evaluate the effect of random luminance noise on the various matrix techniques. The measured *x*, *y*, and *Y* values were first calculated from a given set of spectral responsivities of a colorimeter and CRT spectra of 16 different colors, then 1.7 % RMS luminance noise was added to the original *Y* values. Finally, *x*, *y*, and *Y* values (with noise) were converted into tristimulus values, and the corrected chromaticity values calculated using (1) the R matrix in ASTM E1455-92, (2) the R' matrix in ASTM E1455-96 and (3) the Four-Color Method. The simulations were repeated 10 times. The bars show the root-mean-square error and the maximum errors in *x* and *y* after correction by each technique. The results demonstrate that luminance errors significantly affect the ability of conventional ASTM methods to correct for chromaticity errors, but not the Four-Color Method. For calibration purposes, reduced overall uncertainties in the calibrated instrument may therefore result using this matrix correction technique. Measurements of both CRT's and LCD's have demonstrated that the Four-Color Method works well for both types of displays [6,7]. Utilizing the Four-Color Method, the uncertainty in color measurements of displays can be reduced to less than 0.001 in *x*, *y* (~1 ΔE^{*}ab) with respect to a reference instrument.

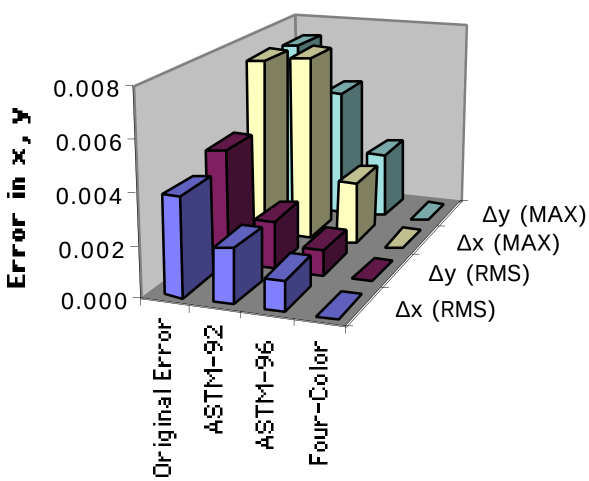

Fig. 2. Chromaticity errors for 16 CRT colors with 1.7 % root-mean-square random luminance noise added to the data, after correction by each matrix method.

III. RESULTS

To evaluate the overall performance of the system, several commercial instruments were calibrated against the NIST reference spectroradiometer for measurement of both a CRT and an LCD. As an example of the results, Fig. 3 shows the errors (differences from the reference instrument) of a tristimulus colorimeter and a diode array system for 14 colors of a CRT. The uncorrected differences in measured chromaticity values between the reference instrument and the commercial instruments were as large as 0.01 for the tristimulus colorimeter and 0.006 for the diode array system for some CRT colors.

Deriving a correction matrix using the Four-Color Method and applying it to the data in Fig. 3 greatly reduces the magnitude of chromaticity errors with respect to the reference instrument. Figure 4 shows the residual errors after correction by the Four-Color Method. In this case, the errors were reduced by approximately an order of magnitude. This method was applied to all the data taken from other test instruments, and similar results were obtained in each case. Based on these measurements, we estimate that calibrated colorimeters can measure any color of a display with an expanded uncertainty (*k*=2) in *x*, *y* of 0.003 and 3 % in *Y* or less.

FPD phosphors generally have very different spectral power distributions from the phosphors used in CRT displays. Instruments are accordingly calibrated for one type of display in particular. If an instrument calibrated for one type of display measures a display with a different phosphor set, the correction by the matrix will not be effective. Care therefore needs to be taken to ensure that the colorimeter has indeed been calibrated for the type of display being measured.

IV. SUMMARY

A calibration facility tailored to color measuring instruments for displays has been established at NIST. Instruments calibrated directly against a particular display in this facility will be able to measure any color of the display with an expanded uncertainty of 0.003 in chromaticity and 3 % in luminance or less. These reduced measurement

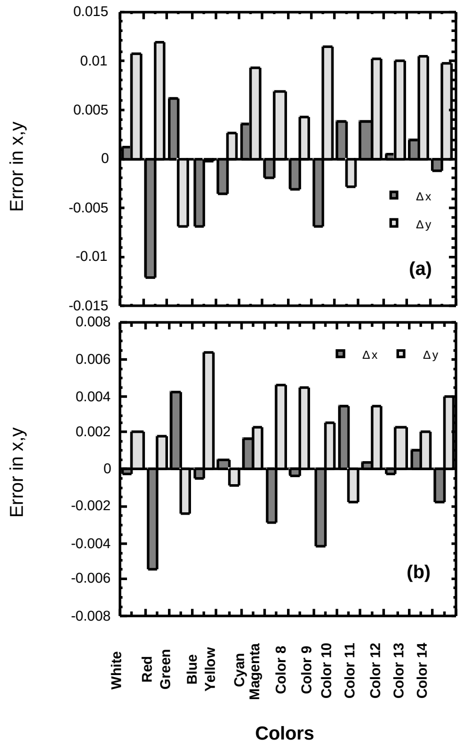

Fig. 3. Errors in chromaticity measurements of a CRT display measured with (a) a tristimulus colorimeter and (b) a diode-array spectroradiometer.

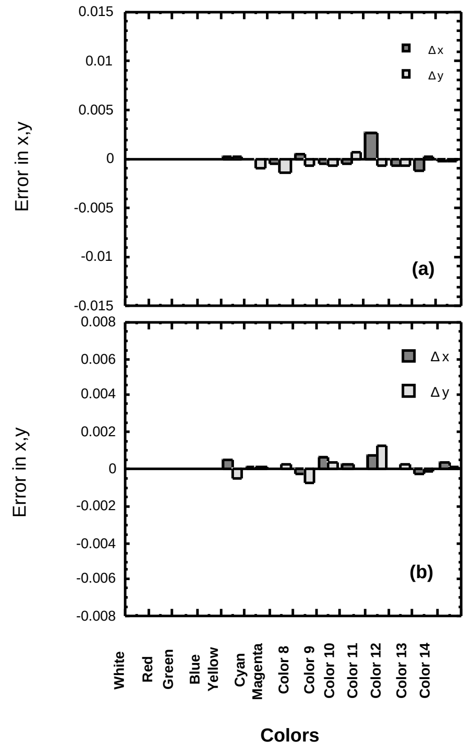

Fig. 4. Residual errors in chromaticity measurements of a CRT Display after correction by the Four-Color Method for (a) a tristumulus colorimeter and (b) a diode-array spectroradiometer.

uncertainties are required for improved accuracy in quality controls and color management for displays. Official calibration services for the color measuring instruments for displays will be available shortly.

V. REFERENCES

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