An Assessment Standard for the Evaluation of Display Measurement Capabilities

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Abstract

A prototype display measurement assessment transfer standard (DMATS) is being developed by NIST to assist the display industry in standardizing measurement methods used to quantify the performance of electronic displays. Designed as an idealized electronic display, the DMATS sources model photometric and colorimetric measurement problems commonly encountered in measuring electronic displays. NIST investigators will distribute calibrated DMATS units to participating laboratories for measurement. Analysis of initial interlaboratory comparison results will provide a baseline assessment of display measurement uncertainties. Also, diagnostic indicators expected to emerge from the data will be used to assist laboratories in correcting deficiencies or in identifying metrology problem areas for further research, such as methods more specific to displays using new display technologies. The paper describes the design, construction and preliminary characterization of a prototype DMATS source. Also, the paper uses the prototype DMATS to illustrate several common measurement deficiencies.

Introduction

The explosion of e-commerce and Internet communication of imagery and graphical information has exposed significant deficiencies in the methodologies employed by the display industry to ensure that color information is correctly communicated to viewers. Other industries such as automotive, medical, textile, cosmetic, paint, and entertainment are critically dependent on their ability to accurately communicate color information to customers. Having come to rely upon modern printing and photographic technologies to preserve the color fidelity of their intended message, these industries are now faced with additional challenges in adapting to the new electronic imaging medium. Industries must address issues related to the accurate reproduction of a product's color on electronic displays, accurate color transportability between print and electronic media, and the potential disparities between the human perception of color versus the physical characteristics of surfaces and illumination geometry. At some level, all industries that depend upon communication of color information — from display manufacturers to web site designers — rely upon quantitative measurements.

However, measuring instruments and the procedures commonly used to measure color and other optical characteristics may not be sufficiently accurate. It is not uncommon, for example, for concern to be raised over small differences between color measurements, in the face of much larger unrecognized errors of 10% to 20 % or more in photometric or colorimetric measurements due to inadequate technique, uncontrolled measurement environment, poorly calibrated instruments, or all of these deficiencies.

NIST is attempting to address the color measurement problem through the development and dissemination of measurement techniques and illuminators equipped with optical targets by which industry technicians can evaluate their measurement methodology and instrumentation. By reducing the laboratory-to-laboratory variance in color and optical measurements, we hope to enable higher accuracy color reproduction, and thus improve and enhance e-commerce.

This paper describes the construction and preliminary characterization of a standard source designed to simulate some of the measurement challenges presented by electronic displays. Several measuring devices are used to measure the DMATS source and examples are provided of measurement deficiencies to be further examined by distributing DMATS units to industrial measurement laboratories

DMATS

NIST has initiated a program aimed at assisting the electronic display industry, including both manufacturers

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and users of displays, in evaluating and advancing the state-of-the-art of display metrology. A series of interlaboratory comparisons is planned in which participants will execute photometric and spectroradiometric measurements of a standard calibrated light source using their typical procedures. NIST analysis of the data will identify measurements exhibiting unacceptably large uncertainties. Such information will be disseminated to industry along with recommendations of measurement methods to reduce the interlaboratory variability among display measurements to support standardization of measurement methods and to enable better specification of display performance.

The central element of the NIST program is a multi-filter-target light source, called a display measurement assessment transfer standard (DMATS), which covers the gamut of electronic display luminance and color. The multi-target source provides a means by which to analyze the

Figure 1. Each DMATS unit will consist of a uniform illumination source with a suite of optical targets mounted in a faceplate, power supply, monitoring devices, and a laptop computer for automatic data logging.

measurement techniques and the measurement environment of participating laboratories. Rather than providing a single calibrated light source, our objective is to provide measurement laboratories with a source with which they can fully characterize their measurement capabilities for their electronic imaging needs.

DMATS Prototype Construction

Several designs were considered for the experimental DMATS. A conceptual DMATS design is shown in Fig. 1. It consists of an illumination source combined with color filters and other optical components selected to emulate many of the measurable attributes of electronic displays. Principal design criteria included low cost, robustness for shipping and handling, and selection and positioning of filter targets so as to fully exercise display measurement apparatus and technique.

Illumination Source

The illumination source was constructed by mounting two tungsten-halogen bulbs into a closed-cell white polystyrene foam box. The box is equipped with baffles at appropriate positions to block direct illumination by the lamps of the rear surface of the box. Such polystyrene foam sources have been shown to be remarkably uniform and to maintain uniformity even with moderate physical abuse [1], an important feature for the experimental unit and those to be used for initial interlaboratory comparisons. It is noted that some later version of the DMATS might very well use a more conventional integrating sphere. Such polystyrene boxes, however, are easily modified for experimental purposes.

The two tungsten-halogen bulbs are powered by a regulated DC power supply supplying the bulbs with constant current of 1.83 A at approximately 30V. The power supply is programmable and equipped with GPIB (general purpose interface bus, IEEE-488.2) interface for its eventual control via a laptop computer to be shipped with the DMATS.

Target Faceplate

A further design criterion influenced the configuration of the target array. The DMATS was conceived not merely to provide a set of calibrated standard targets, but to present the targets in a configuration representative of display measurement situations. Hence the targets are arranged in a planar array and to some extent juxtaposed in order to challenge the metrologist's ability to avoid contamination of measurements from adjacent regions. Narrow-band and wide-band interference filters cover the color gamut while wide-band glass filters provide interior points within the gamut. Polarizers, differing in density and orientation, test the polarization sensitivity, while neutral density filters test the linearity of the measuring device. Opaque white and gloss black targets provide indicators of the measurement environment and the sensitivity of the instrumentation to glare. Grilles, gray grilles, and a mura (non-uniformity) target test the detail measurement capabilities of the laboratories. Various cutoff filters test the out-of-band or band leakage in the measuring instrumentation.

Light Source Monitors

The DMATS source is equipped with two calibrated silicon photodiode detectors, one fitted with a photopic correction filter, to monitor the light source. Data recorded from these two detectors are used to determine lamp stability and provide a reference for the measurements. The outputs of these detectors are monitored via picoammeters, also equipped for automatic logging to the computer via GPIB ports.

Temperature Monitor

The temperature of the faceplate is monitored with a thermometer or thermocouple probe to provide additional data on environmental factors having potential effects on measurements.

Preliminary Characterization

Initial characterization of the DMATS prototype was aimed at: (1) determining the temporal stabilization baseline of the unit; (2) measuring the uniformity of the illumination source including evaluation of the suitability of interior surface materials; (3) making a coarse measurement of the luminance and tristimulus color coordinates of the filters targets; and (4) an initial assessment of the effects of the inevitable warming of the faceplate and targets. Unless otherwise noted, all measurements were taken in a darkened room and through the 2.54 cm aperture of a gloss-black frustum positioned close to each target in order to reduce the effect of veiling glare and contamination of measurements by adjacent targets [3].

Stabilization Baseline

In order to reduce the uncertainty in subsequent characterization measurements we first determined the "warm-up" period needed for the tungsten sources to reach a steady state and for the faceplate to reach a stable operating temperature. The DMATS was positioned such that the luminance at the center of the exit port could be measured using a luminance meter.

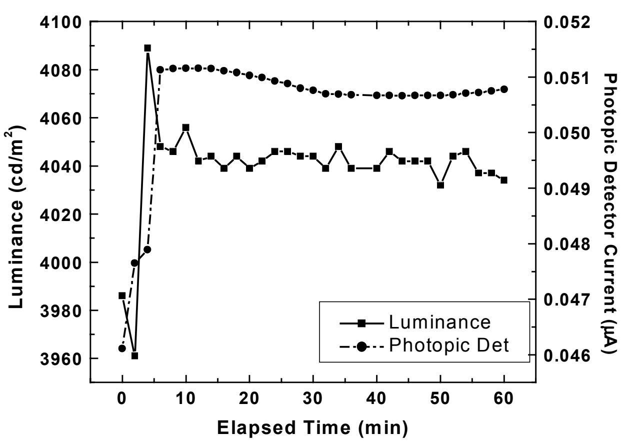

Figure 2. Luminance and photopic detector as a function of elapsed time of system "warm-up."

In Fig. 2 are plotted the luminance at the exit port and the current output of a photo-detector equipped with photopic filter and aimed at the rear of the light-integrating enclosure. A similar temporal response pattern was observed with luminance and correlated color temperature as measured with the spectroradiometer. These data indicate that the illumination source is stable after approximately 30 minutes of operation. Once the stabilization baseline was determined, subsequent measurements were performed following a warm-up period of 30 minutes.

Spatial Uniformity of Illumination Source

Luminance uniformity of the polystyrene foam box was tested using three different materials for the rear surface: (1) the untreated interior of the box, i.e. 5 cm bulk polystyrene foam; (2) a 2.5 cm thick insert of styrofoam having one untreated surface and (3) a surface coated with barium sulfate ($BaSO_4$) paint. Each material was tested without the faceplate and with the faceplate in position, but without filters mounted. A final uniformity measurement was made with the faceplate mounted and all filters mounted except that the corner filters were replaced with clear glass. Using a motorized positioning system, the DMATS source was moved in x and y directions such that measurements could be made at the four corner faceplate positions and at the center. The 5-point measurement pattern was repeated 5 times.

The results are summarized in Fig.3. The rear surface material is shown on the abscissa of the box plot with the averages of 25 measurements indicated by solid square symbols. The thickness of each box represents the bounds within which 50% of the measurements are contained, and is accordingly a non-parametric measure of the dispersion, and a general measure of the uniformity. The standard deviations are also shown in the figure. Also shown are the percent maximum non-uniformity, computed as the maximum difference among the five-point averages divided by the grand mean.

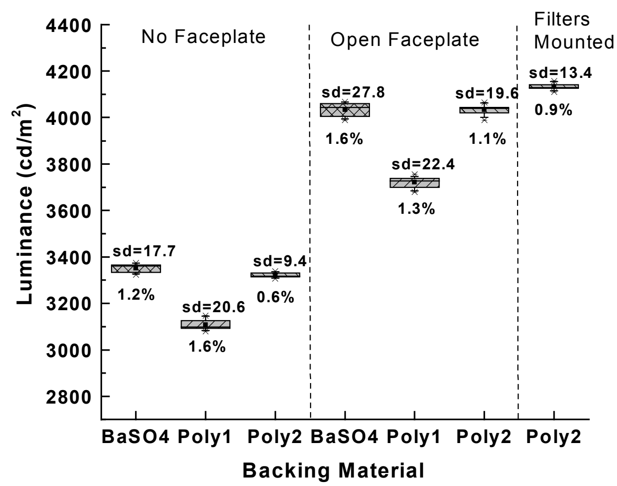

Figure 3. Comparison of luminance and relative degree of illumination uniformity for each of three rear surface materials.

It is remarkable that the raw, untreated polystyrene-foam surface of the box interior (i.e., "Poly2") compares favorably in luminance to the $BaSO_4$ coating. Moreover, the polystyrene foam tends to be more uniform than the $BaSO_4$ surface in all faceplate conditions. It exhibits less than 1% non-uniformity in all configurations. Of course, the luminance non-uniformity of the $BaSO_4$ surface may be related to the non-uniformity in the thickness of the coating, which was applied manually. Regardless, however, it is clear that despite its slightly higher reflectance, the barium sulfate offers no uniformity advantage over the natural interior of the integrating box. The comparatively lower luminance of the 2.5 cm polystyrene-foam sheet ("Poly1") may be related to its being thinner or due to other unquantified differences from the material of the box. The $BaSO_4$, however, is used effectively to coat the interior surface of the faceplate as is evidenced by the marked increase in luminance when the empty faceplate is mounted.

DMATS Application

High precision characterization of the DMATS prototype will be completed prior to the initial interlaboratory comparison which is scheduled to begin late calendar year 2000. Several in-house measurements were performed on the DMATS to demonstrate how it might be used to diagnose instrument or methodological problems. The instruments used have not been recently calibrated. Any resulting dispersion in the measurement results, therefore, represent what we might expect from a poorly maintained measurement laboratory involved in display measurements. How well these measurements can be improved by careful calibration remains to be seen and will be a subject of a future paper.

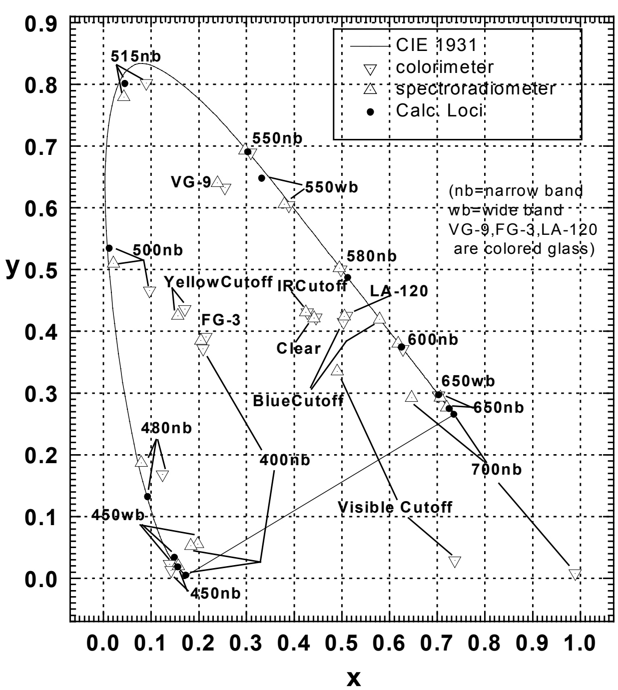

Figure 4. Chromaticity coordinates of filter targets on CIE 1931 spectrum locus as measured by two instruments.

Color Coordinates of Filter Targets

Luminance and x, y chromaticity values of bandpass and cutoff filters were measured with a tristimulus filter colorimeter and with a photodiode array spectroradiometer. The Commission Internationale de l'Eclairage (CIE 1931) (x, y) chromaticity coordinates measured by the two instruments are shown in Fig. 4. Also, calculated theoretical loci for the narrow band and wide band interference filters are shown for comparison. Some fairly large disparities are evident both between the two instruments and between theoretical and measured loci. Boynton et al., [2] discuss the use of interference filters to characterize colorimeters and spectroradiometers. Moreover, they suggest how the displacement vector of measured values from theoretical values may be diagnostic of particular sources of measurement error, such as bandwidth scattering or spectral mismatch of the tristimulus filters.

Temperature Effects

The ventilation scheme for the prototype DMATS enabled moderate control of the faceplate temperature, but we were concerned over possible effects on measurements of elevated temperature. We performed a preliminary examination of this by recording measurements of chromaticity coordinates both with and without active cooling via exhaust fans. Figure 5 shows coordinates as measured with the colorimeter at two temperatures and the calculated positions of the interference filters for reference. At the level of resolution afforded by the colorimeter, there does not appear to be a noticeable effect of heating the faceplate. Additional testing is planned, however, using a double grating monochromator.

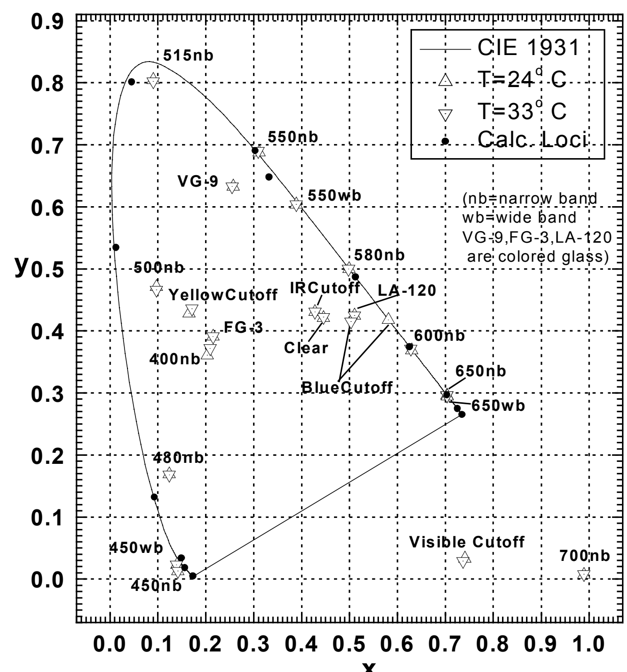

Figure 5. Effect of temperature on x,y coordinate measurements

Stray Light and Veiling Glare Effects

Figure 6 shows chromaticity coordinates measured with a tristimulus filter colorimeter. Measurements were made both with and without use of a glossy-black frustum to

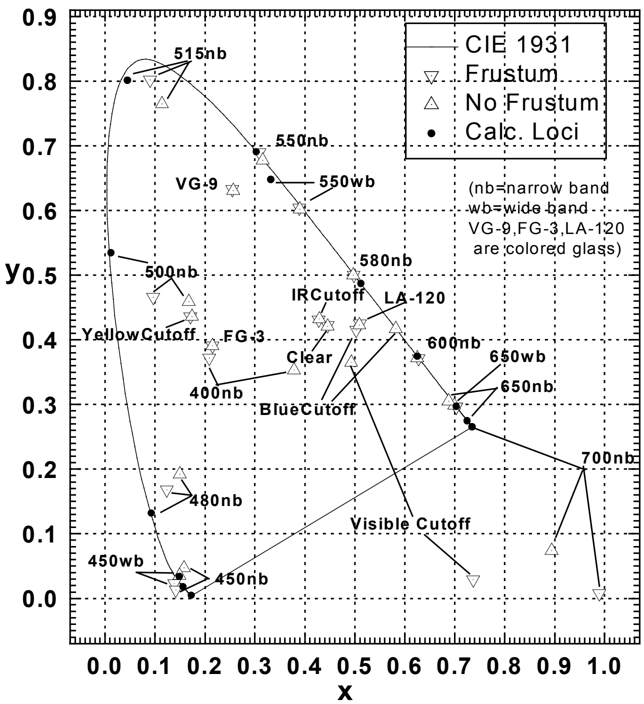

Figure 6. Colorimeter measurement with and without use of frustum.

reduce the stray light impinging on the colorimeter from adjacent areas of the DMATS faceplate.

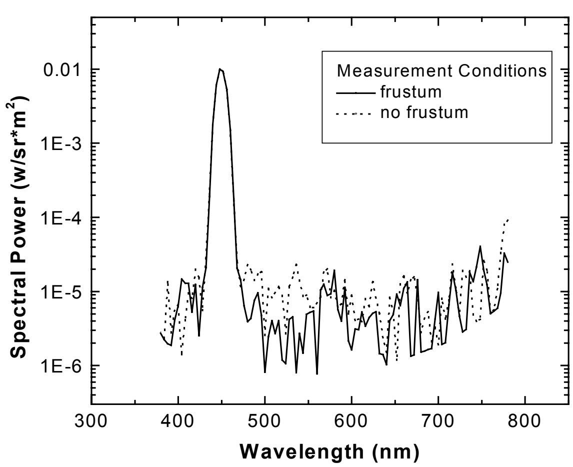

Figure 7. Spectrum of 450nm narrow band interference filter measured by spectroradiometer using gloss black frustum to reduce stray light effects

Similarly, measurements were made using a spectroradiometer both with and without the frustum mask. Figure. 7 shows the spectrum of a narrow-band interference filter with center wavelength of 450 nm and a full width at half maximum (FWHM) bandwidth of 10 nm. The measured peak wavelength is not displaced noticeably, at least within the 4 nm resolution of the instrument. However, out of band power is increased causing a shift in the measurement of chromaticity coordinates of the 450 nm narrow band filter.

Conclusion

If the disparities persist even after recalibration of instrumentation, then this program will have revealed a serious and fundamental problem in display metrology. Before we can worry about subtle color measurements and rendering among different display technologies, we first must develop ways to reduce errors in color measurements. Otherwise, errors in instrumentation or its use may be incorrectly attributed to the display.

References

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