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28.2: Display-Measurement Round-Robin

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ABSTRACT: Display measurement procedures intended for use by other laboratories and by industry for measuring, analyzing, and reporting the performance of display monitors are tested through the round-robin process in preparation for acceptance of the procedures as a standard. The National Information Display Laboratory (NIDL) and National Institute of Standards and Technology (NIST) results presented here show much quantitative agreement in support of the measurement procedures. Interpretation of the few discrepancies will be the subject of a later report along with any attendant proposed refinements to the measurement and reporting procedures.

Objective and Background

The objective of this round-robin exercise between NIDL and NIST is to evaluate selected procedures for photometrically measuring, analyzing and reporting the capabilities of monitors to accurately display high-resolution, monochrome and color gray-scale imagery for both text and graphics. A successful implementation of the procedures by other laboratories improves the likelihood of gaining acceptance by a commercially-recognized standards organization.

The goal of NIDL's document is not to reinvent, but to identify, incorporate, and revise as appropriate, measurement standards that other standards-generating bodies have established. Existing standards, however, only provide methods for measuring and evaluating displays targeted for text or graphics applications, and do not produce sufficient information to adequately differentiate between candidate high-performance displays. The ultimate goal of establishing such measurement and reporting standards, and promoting their use, is to provide a common language by which display users can communicate their display needs to manufacturers.

Results to be Presented

The present study applies the NIDL measurement procedures (1,2) for evaluating the photometric, resolution, and geometric performance of a Commercially-available Off-The-Shelf (COTS), high-resolution (1600 x 1200 addressability) color display monitor (3,5) using COTS measurement equipment including a spectroradiometer, CCD (charge coupled device) camera, photodiode linear array, and computer-controlled positioner system. The measurements were performed on the same monitor by two independent laboratories located at NIDL and at NIST. A summary of the results are presented in Table 1. All uncertainties are expanded uncertainties with coverage factor k=2 where the combined standard uncertainties are based on a root-sum-of-squares of all uncertainty components. %DEV/DIFF is the deviation between NIDL and NIST results expressed as a percentage, or the absolute difference, expressed either in fractions of a pixel or as a difference of percentages. Deviations between laboratories sometimes exceed anticipated measurement uncertainties. This should not be alarming since the characteristics of a monitor can change with age and handling.

Table 1. Summary performance comparison

	NIDL	%DEV/ DIFF	NIST	Uncer-tainty
Warmup time (min)	80	13.3%	70	24%
System Gamma, White	2.43	1.2%	2.40	3%
Red	2.55	6.5%	2.39	3%
Green	2.38	0.0%	2.38	3%
Blue	2.43	2.4%	2.49	3%
Luminance Stability	7.6%	0.6%	7.0%	4%
Luminance Uniformity	17.9%	1.7%	16.2%	2%
White Uniformity, Δx	2.0%	0.8%	2.8%	1%
Δy	2.8%	0.6%	3.4%	1%
Linearity (pixels) H	4.0	1.1	2.9	1.0
V	4.0	0.8	4.8	0.7
Linewidth (pixels)				
Center H	1.2	0.1	1.3	0.1
V	1.1	0.1	1.2	0.1
Avg periphery H	1.4	0.1	1.5	0.1
V	1.2	0.0	1.2	0.1
Worst periphery H	1.6	0.1	1.7	0.1
V	1.4	0.2	1.2	0.1
Location	10:00		10:00	
Blue-Red Conv. (pixels)				
Center H	0.3	0.2	0.5	0.2
V	0.3	0.3	0.0	0.2
Avg periphery H	0.3	0.9	1.2	0.2
V	0.4	0.1	0.3	0.2
Worst periphery H	1.1	0.8	1.9	0.2
V	0.3	0.0	0.3	0.2
Location	3:00		2:00	
Contrast Modulation				
(White, Center) H	36%	4%	40%	7%
V	34%	5%	39%	5%

Photometric Characterization

Warmup Characteristics

The luminance of the full screen set to full white (255 input level) was measured at screen center for a period of two hours. The data are presented in Figure 1. The warmup time is defined as the earliest time for which the luminance curve stays within

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±1% of the final value L(120 min). The small slope of the luminance curve with respect to time provides for a large uncertainty estimated at 12%.

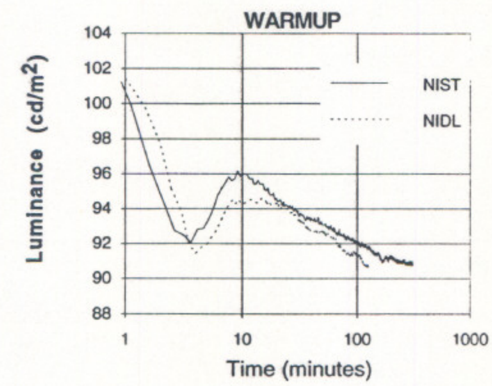


Fig. 1. From a cold start, the monitor under test required approximately 75 minutes for luminance at input level 255 to stabilize to within 1%. NIDL/NIST results agreed to within 13.3%. (Note suppressed zero on luminance scale).

System Gamma

Luminance at center screen for a 1% screen area rectangular target was measured for a large number of different input voltage levels. Figure 2 presents the white data. A linear fit was applied to the high-end luminance data for white between counts 20 and 255 to derive a gamma value. The system gamma is defined as the slope of the curve in the log-log plot.

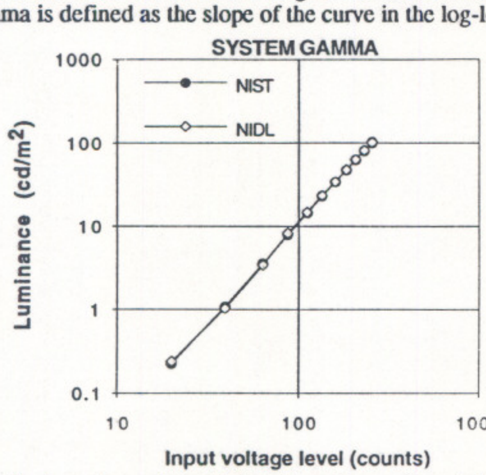


Fig. 2. Log-log plot of input voltage (counts) versus luminance for white showing overlap of NIDL and NIST data points. Gamma values obtained between counts 20 to 255 were 2.43 at NIDL and 2.40 at NIST.

Luminance and White Uniformity

Luminance and chromaticity coordinate measurements were taken at nine screen positions at maximum luminance setting for a full-screen white field. The variation in luminance was found to be 17% screen average. NIDL/NIST results agreed to within 1.7%. Data are plotted in Figure 3.

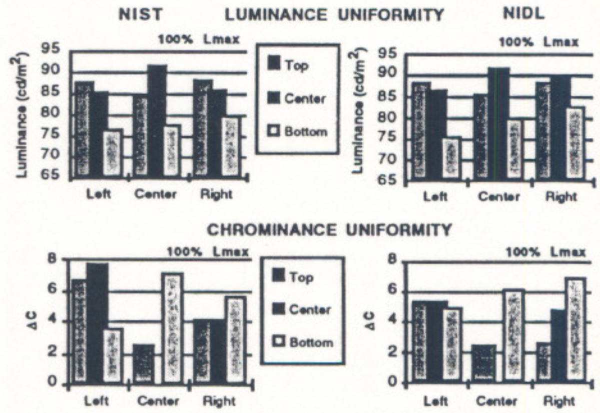


Fig. 3. The luminance varies by 17% across the screen at the highest luminance setting. NIDL/NIST luminance uniformity results agreed to within 1.7%. NIDL/NIST measurements indicated chroma differences across the screen of 7 and 8 ΔC units, respectively, in CIE (International Commission on Illumination) Luv space. A color difference of 5 ΔC units is clearly distinguishable.

Luminance Stability versus Fill Factor

Center screen luminance was measured for different-sized white patches on a black background (different fill factors). The luminance increases with fill factor (increasing percentage of screen that is white) by about 7%. Agreement between NIDL/NIST results was 0.6%.

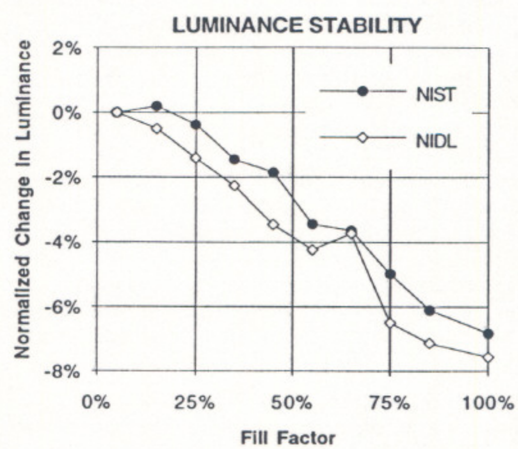


Fig. 4. The luminance increases with fill factor (increasing percentage of screen that is white) by about 7%. Agreement between NIDL/NIST results was 0.6%.

Resolution Characterization

Linewidth

The linewidths (full width at half height) of vertical and horizontal white lines were measured at nine screen positions with the input voltage level set at the input count level that provides 50% maximum luminance on a full screen. In order to account for the variation in apparent linewidth caused by the sampling of a color CRT (cathode ray tube) phosphor screen, linewidths measured by NIDL are taken on single-pixel-wide lines successively moved by one pixel width to seven different locations. Linewidths reported by NIST are for a single pixel position. The data are shown graphically in Figure 5. Horizontal linewidths grow by approximately 20% from center to periphery.

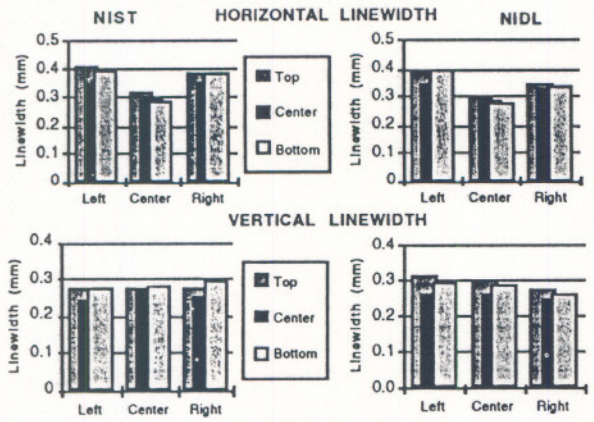


Fig. 5. Linewidths (in mm) of white lines displayed on the monitor under test. Horizontal and vertical linewidths at screen center are 0.29 x 0.27 mm, or 1.23 x 1.18 pixels. H x V linewidths at average periphery are 0.35 x 0.28 mm, or 1.49 x 1.22 pixels. NIDL/NIST results agree to within 0.2 pixel.

<u>Contrast Modulation</u>

Contrast modulation was measured in both horizontal and vertical directions at screen center for white for a range of screen luminance settings. The highest video modulation frequency was examined by displaying grille test patterns consisting of alternating lines with 1 pixel on, 1 pixel off. Here, the "off" pixel was always set at the input voltage level (count 0) providing 0% maximum luminance, while the voltage and count level of the "on" pixel was adjusted to provide 25%, 50%, 75%, and 100% maximum luminance. Contrast modulation, $C_m(\text{out})$, was calculated using relative values of peak and valley luminance subjectively determined from the measured luminance profiles.

$$C_m(\text{out}) = (L_{peak} - L_{valley}) / (L_{peak} + L_{valley}) \qquad (1)$$

For the 1-on/1-off pattern, the horizontal modulation (vertical grille) drops as low as 34% at the highest luminance setting (Figure 6). Contrast modulation is further degraded by the presence of moiré.

The subjective technique for determining L_{peak} and L_{valley} cannot, however, be applied to all sets of measurements. For some luminance patterns the subsidiary peaks appear only as shoulders, or are altogether absent. Values of L_{peak} or L_{valley} suitable for use in (1) above for $C_m(\text{out})$ cannot then be obtained in an objective and reliable way. A second technique that is based on the Fourier transform of the luminance pattern (4) is recommended by NIDL because it can be used to infer an objective value of the MTF (modulation transfer function) regardless of the shape of the modulation pattern.

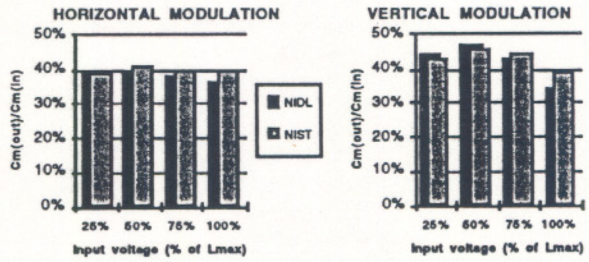


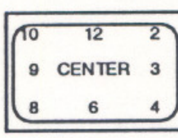
Fig. 6. Contrast modulation results for white 1-on/1-off grille patterns displayed at screen center. Agreement between NIDL/NIST results was within 5%.

<u>Convergence</u>

Blue-to-red misconvergence in both horizontal and vertical directions was measured at nine screen positions. Data are compared in Table 2. Input voltage was set at maximum level to sequentially display blue and red three-pixel-wide vertical and horizontal lines. Multiple pixel-width lines (3 to 5 pixels) are used to reduce the impact of shadowmask sampling to improve measurement repeatability over single-pixel lines. NIDL and NIST results agree that horizontal and vertical separations measured at screen center are less than 0.5 pixel. Results are also in agreement for vertical separations which averaged less than 0.5 pixel over the periphery of the screen. Results did not agree well, however, for horizontal separations averaged over the screen periphery. Horizontal separations measured by NIST at the screen periphery positions averaged 1.16 pixels compared to less than 0.5 pixel measured by NIDL. Horizontal misconvergence is believed, therefore, to have drifted during the course of the round-robin.

Table 2. Blue to Red Misconvergence (in mm). Nominal pixel size is 0.235 x 0.229 mm (H x V).

	NIST measurements		NIDL measurements	
Position	Horiz	Vert	Horiz	Vert
center	0.11	0.01	0.08	0.08
12	0.26	-0.02	0.02	0.07
6	0.20	-0.12	-0.03	-0.08
3	0.06	0.10	0.26	0.06
9	0.32	-0.05	-0.09	-0.01
2	0.43	0.06	0.01	0.22
4	0.34	0.03	-0.08	0.06
8	0.27	0.04	-0.05	0.10
10	0.30	-0.15	0.04	-0.08



Key to clock positions used in the tables

Geometric Characterization

Linearity

The non-linearity of the scan was about 0.2% of full screen horizontally and about 0.4% vertically. The linearity of the raster scan is determined by measuring the positions of equally spaced lines. The deviations from linearity were determined by fitting a straight line through the two data points on both sides of zero to define the pixel size (linear term) at the center and any zero offset between the measurement apparatus and the screen. The non-linearity shown in Figure 7 was determined by subtracting the computed position, using the above linear fit, from the measured data.

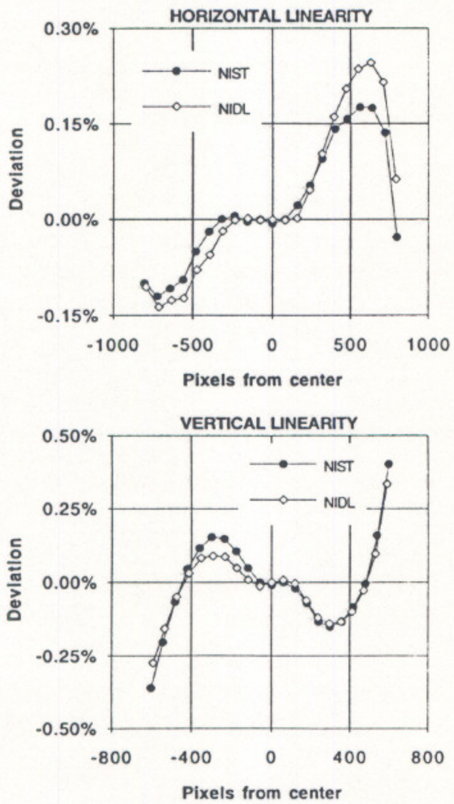


Fig. 7. Linearity characteristics of monitor under test. The maximum non-linearity of the scan was about 0.2% of full screen horizontally and about 0.4% vertically. Agreement between NIDL/NIST results was within 0.4%.

Impact

The NIDL measurement procedures were submitted to the Electronics Industries Association for review and scrutiny in May 1994. A round-robin measurement was proposed. NIST agreed to evaluate the procedures and compare results with NIDL. NIDL and NIST measurements agree on most performance measures. Discrepancies exist in misconvergence around the display periphery and in chrominance uniformity at the sides of the CRT. These discrepancies will be the subject of a later report along with any attendant proposed refinements to the measurement and reporting procedures. Because of changes in a monitor's characteristics, certain features like misconvergence may not be reliably set at one time and be expected to stay constant as a monitor is shipped from one location to another. These measurements suggest that further procedures need to be established which pay more attention to initially checking the monitor for proper setup.

Commercially-accepted procedures for quantitatively and objectively measuring and reporting the performance of display monitors would provide an easy-to-use, common format and unambiguous terminology for softcopy users to specify their needs to display manufacturers. Widespread utilization of these procedures and reporting of display performance would enable users to easily, rapidly, and comprehensively identify all monitors for consideration, compare their performance, and choose, install, and adjust the most appropriate display system for the user's application and environment. Finally, commercially-accepted display measurement standards would minimize "specsmanship" and spur competition and innovation, leading the commercial industry to provide higher performance products of importance to commercial markets and to the government.

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5. Any commercial item referred to in this paper is for the purpose of identification only. Such a reference does not imply a recommendation or endorsement by either the National Institute of Standards and Technology or the National Information Display Laboratory, neither does it suggest suitability to task.