SID
SOCIETY FOR INFORMATION DISPLAY

SOCIETY FOR INFORMATION DISPLAY

2007 INTERNATIONAL SYMPOSIUM

DIGEST OF TECHNICAL PAPERS

VOLUME XXXVIII, BOOK II

LONG BEACH CONVENTION CENTER
LONG BEACH, CALIFORNIA
WEDNESDAY, THURSDAY & FRIDAY
MAY 23-25, 2007

20.1: *Invited Paper:* Metrology and Robustness of Bright-Room Contrast Measurements

Edward F. Kelley
National Institute of Standards and Technology*

Abstract

Bright-room contrast measurements methods are being proposed by standards committees to characterize flat panel displays for living-room ambient environments. Some proposals involve creating a room with an overhead light. By modeling the room as a sphere, we show how such room-based measurement methods can be very irreproducible. Such methods can be modified and made robust by making direct-source measurements combined with integrating-sphere-based diffuse reflectance measurements.

1. Introduction

Several standards organizations are attempting to include a so-called "bright"-room contrast measurement method to characterize a flat panel display (FPD) under ambient environments that might be found in a typical living room, where the FPD is used for viewing television or movies. (Because these standards are in the development stage, we are not at liberty to reveal their identity and content.) We are starting to see manufacturers of FPDs include a bright-room contrast metric with their display specifications. One goal of good metrology of displays is to provide measurement methods that allow reproducibility to be reasonably easy to achieve. We call these robust measurement methods, and ambient-contrast measurements should especially be robust.

Some have proposed placing the display in a room that contains a single ceiling lamp and measuring the contrast of the display with a certain placement of the display under the ceiling lamp providing the display surface with a specified illuminance. We will develop a model for such an arrangement and show how sensitive the room-based measurement result is for changes in the wall reflectance, the size of the room, and the exact angle between the center of the ceiling lamp and the center of the display. This will demonstrate that such a room-based measurement is not robust, in that reproducibility will require such careful attention to the configuration of the room that many workers/researchers will not tolerate the constraints that robustness will impose upon the room and the apparatus alignment. Using an integrating sphere or sampling sphere combined with a directed-source measurement will provide much better robustness and control of the measurement conditions, and would therefore be preferable to room-based measurements.

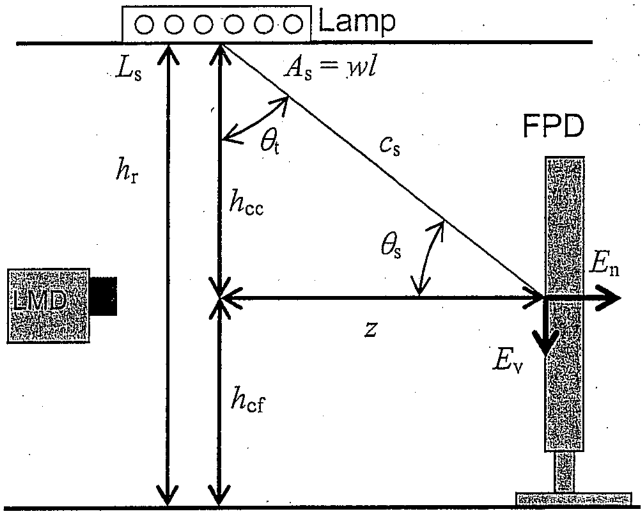

Figure 1 . Room configuration with fluorescent ceiling lamp.

2. Room Model

Consider a room with average diffuse reflectance ρ_e for all surfaces (walls, ceiling, and floor; the "e" is for "enclosure" to avoid a "w" subscript that can be confused with an abbreviation for "white"). Figure 1 shows the center of a FPD placed at a distance c_s from the center of the ceiling lamp so that the source angle is θ_s. The lamp consists of several fluorescent bulbs (six shown). The illuminance from the lamp and the room at the center of the screen is E_n when measured with the illuminance meter pointing in the direction of the screen normal and E_v when pointing vertically. The various distances would be specified in the standard, and the light-measuring device (LMD; a luminance meter, spectroradiometer, etc.) would be near the normal of the screen but avoiding measuring a specular image of itself or other objects brighter than the wall. Note that avoidance of a specular image of the LMD (as well as the operator, tripod, room objects, etc.) suggests such an image is available, which is not always the case. Many liquid-crystal displays (LCDs) have a microstructure on the front surface—an anti-glare treatment—that produces a reflection property known as haze. Haze will produce a reflected luminance that is sensitive to the luminances of anything anywhere in the vicinity of the specular direction—in this case nearly the normal direction. The introduction of a non-trivial haze—in itself—would make this room configuration unsuitable for making reproducible measurements. [1] This will be proven by our model.

Suppose that the lamp produces an illuminance E_s at the center of the screen. Some standards specify a certain ratio E_v/E_n of illuminances at the screen center, while others might specify the geometry; here we will specify the geometry such that

$$\theta_s = \tan^{-1}(h_{cc}/z) = 35°. \tag{1}$$

Assuming that the lamp is a Lambertian source with a rectangular size of width w and length l, the area is $A_s = w\,l$. The flux Φ_s output of the lamp is related to its luminance L_s by

$$\Phi_s = \pi L_s A_s. \tag{2}$$

For simplicity, we will show the lamp as a white integrating sphere with a round exit port having an area A_s and luminance L_s in our room model. We will place this sphere source in an imaginary

---

* Optoelectronics Division, Electronics and Electrical Engineering Laboratory, U.S. Department of Commerce. This is a contribution of the National Institute of Standards and Technology, and is not subject to copyright.

ISSN/007-0966X/07/3802-1034-$1.00 © 2007 SID

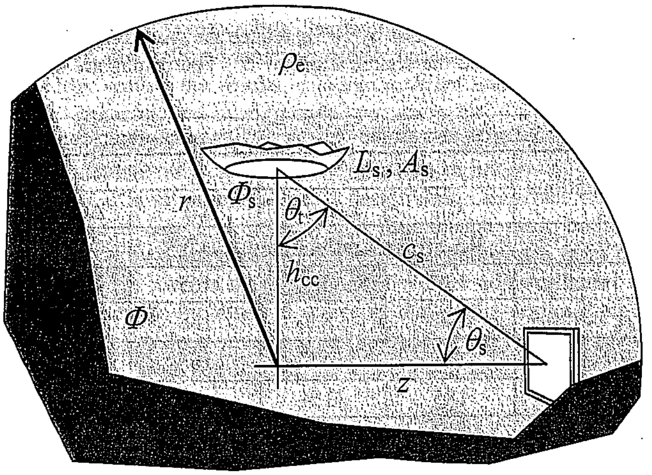

Figure 2. Spherical room model with interior diffuse reflectance ρ_e and radius r. The lamp is shown above the center of the sphere in the drawing, but that is not necessary. The radius r can be smaller than z as long as the lamp and display fit within the sphere.

spherical room so we can calculate the diffuse contribution from the flux input of the lamp—see Fig. 2. For the purposes of this model, we will assume the display is off and does not seriously perturb the interior flux. In practice, this would of course not be the case. Our simplified model will afford us an analytical means to calculate how the measured reflection is influenced by the room characteristics.

The illuminance E_s directed at the center of the screen from such a lamp is given by

$$E_s = L_s\Omega_s\cos\theta_t = L_s(A_s/c_s^2)\cos\theta_t = L_s(A_s/c_s^2)\sin\theta_s, \qquad (3)$$

where $\Omega_s\cos\theta_t$ is the projected solid angle of the lamp from the screen center, and

$$c_s = \sqrt{h_{cc}^2 + z^2} \qquad (4)$$

is the distance between the lamp center and screen center. The illuminance incident on the screen surface is a combination of the diffuse illuminance E_d and the directed illuminance E_s from the lamp accounting for the screen tilt with respect to the lamp:

$$E_n = E_s\cos\theta_s + E_d. \qquad (5)$$

The diffuse illuminance in a spherical room with radius r and no exit port arises from the total luminous flux Φ given by [2]

$$\Phi = \Phi_s / (1-\rho_e), \qquad (6)$$

where we consider Φ_s to be the only source of flux in the room. The uniform diffuse illuminance E_d on the interior wall is

$$E_d = \Phi/S = \frac{L_s A_s}{4r^2(1-\rho_e)}, \text{ [lx]} \qquad (7)$$

where $S = 4\pi r^2$ is the surface area of the sphere. Right away we are seeing some of the problems with using a room. The uniform diffuse illuminance is very sensitive to changes in the size (radius) of the room. The wall reflectance must also be carefully regulated as would the luminance of the lamp. The illuminance on the screen surface becomes

$$E_n = L_s A_s \left[\frac{1}{4r^2(1-\rho_e)} + \frac{\sin\theta_s\cos\theta_s}{c_s^2} \right]. \text{ [lx]} \qquad (8)$$

The first term in the brackets is proportional to the diffuse contribution from the room, and the second term is proportional to the direct illuminance from the lamp. If a standard promoting this method provides a target illuminance, say E_n =100 lx, then the luminance of the lamp is adjusted until that illuminance is achieved. However the ratio of the directed illuminance to the uniform diffuse illuminance is the ratio of the two terms in the brackets and is fixed by the room-source geometry. Even if the target illuminance is set correctly, the ratio between the two sources of illuminance depends upon the room-source geometry, whereby different displays will respond differently to the environment as the room characteristics (r and ρ_e) change from laboratory to laboratory. If a standard specifies that a target illuminance ratio E_n/E_v be established, then in addition to adjusting the luminance of the lamp, the placement of the display (h_{cc}, z) and source angle θ_s will have to change depending upon the room characteristics. For the purposes of this model, we will assume that an illuminance level for E_n is to be fixed. This requires the luminance of the lamp be adjusted to

$$L_s = \frac{E_n}{A_s} \left[\frac{1}{4r^2(1-\rho_e)} + \frac{\sin\theta_s\cos\theta_s}{c_s^2} \right]^{-1} \qquad (9)$$

for any change in the room size r, its reflectance ρ_e, or the angle of the directed source θ_s.

Consider the display showing color D, where D is either "W" for white or "K" for black. For simplification purposes, we will assume that our displays have the same reflection properties independent of color—that is not true in general. Suppose our display has a diffuse reflectance of ρ for the uniform diffuse illuminance, and a luminance factor of $\beta_{\theta s/0}$ for a directed source at angle θ_s from the normal and the detector located on the normal. The luminance K_D of the screen with reflections for color D is

$$K_D = L_D + \frac{\rho}{\pi}E_d + \frac{\beta_{\theta_s/0}}{\pi}E_s\cos\theta_s, \qquad (10)$$

where L_D is the luminance of the screen as measured in a darkroom exhibiting a color D. (To simplify the model, we continue with the assumption that the display doesn't modify the interior flux of the sphere.) The ambient contrast will be given by

$$C_A = K_W/K_K. \qquad (11)$$

We wish to examine how sensitive the ambient contrast is to changes in three parameters: the wall reflectance ρ_e, the angle θ_s of the directed source, and the size r of the room. The expressions for the relative changes in the ambient contrast as a function of any parameter are very complicated and little is served by reproducing them here. Not only is there an explicit dependence upon these parameters in the expressions for the illuminances, but there is an additional implicit dependence upon them because L_s changes as these parameters change in order to maintain E_n at the chosen level—see Eq. (9). We can now apply this model to actual displays to see how nonrobust the room-based measurement will be. We will calculate the ambient contrast for typical displays and room values, and then adjust the values slightly to test the robustness associated with the parameters.

3. Model Application to Displays

Suppose we require that the illuminance $E_n = 100$ lx. Let us apply the above results to a plasma display panel (PDP) and a liquid crystal display (LCD). The bidirectional-reflectance distribution functions (BRDFs) associated with these displays are shown in Fig. 3. The PDP BRDF shows a quasi-Lambertian behavior away from the specular direction, and the delta-function behavior indicates that the display will show a distinct virtual image of the source in the specular direction. The specular reflectance for this PDP is $\zeta = 0.040$ and the diffuse reflectance (specular included) is $\rho_{PDP} = 0.0925$ as measured 10° from the left of the normal of the display. (The relative expanded uncertainty with a coverage factor of two for all measurements in this paper is estimated to be 5 %.) The LCD BRDF shows sensitivity to the luminance of any object in the vicinity of the specular direction, and will not show a distinct virtual image of any source, but only a fuzzy (diffused) representation of a source in the specular direction. The LCD is also much less sensitive than the PDP to sources of light away from the specular direction beyond approximately 20°. The LCD has a diffuse reflectance of $\rho_{LCD} = 0.155$ at 10° from the left of normal (it is an old LCD; newer LCDs exhibit substantially less diffuse reflectance than this—roughly one third of this value). The luminance factor ($\beta = \pi B$) at 35° for the LCD is 0.0127, and for the PDP it is 0.0606. Thus these displays will respond very differently to different illumination conditions. We will assume that both displays exhibit the same darkroom luminances $L_W = 500$ cd/m^2 and $L_K = 0.5$ cd/m^2.

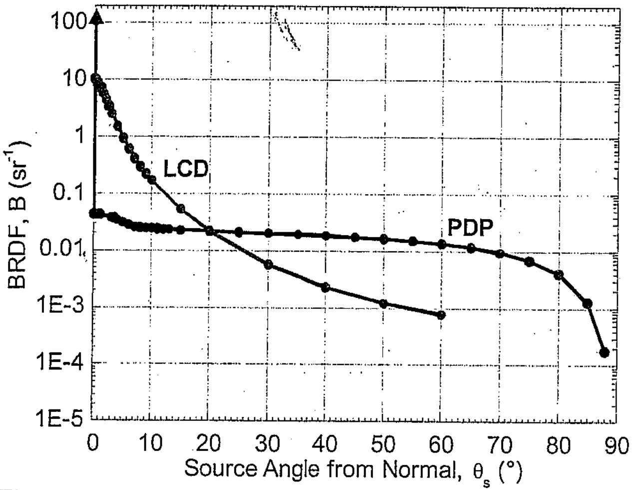

Figure 3. Comparison of the BRDF for a PDP and a LCD on a log scale for the ordinate. The quasi-Lambertian nature of the PDP is indicated by the almost flat region covering most of the range of angles. The arrow at zero of the PDP BRDF indicates the delta function that is associated with the specular component of the PDP BRDF. The LCD BRDF doesn't exhibit a specular component (which would make a distinct image of the source) and consists only of haze. [1]

We assume (1) a ceiling lamp having dimensions $w = 0.610$ m and $l = 1.219$ m, (2) a placement geometry of $h_{cc} = 1.7$ m and $z = 2.43$ m, and (3) a room radius of $r = 2.5$ m. We will assume two room wall reflectances, $\rho_e = 0.5$ and $\rho_e = 0.1$. We will calculate the ambient contrast for each room and for each display for these initial situations; then we will recalculate it after separately increasing the room radius by 50 %, reduce the wall reflectance by 20 %, and increase the source angle by 5°. The results are shown in Table 1.

Table 1. Changes in ambient contrast with parameter changes.

Conditions	LCD (old)		PDP	
	C_A	$\Delta C_A/C_A$	C_A	$\Delta C_A/C_A$
Room wall reflectance $\rho_e = 0.5$				
Initially	139	—	165	—
$\rho_e \rightarrow 0.8\rho_e$	147	5.8 %	168	1.5 %
$\theta_s \rightarrow \theta_s$+5°	141	1.4 %	168	0.4 %
$r \rightarrow 1.5r$	185	33 %	177	7.1 %
Room wall reflectance $\rho_e = 0.1$				
Initially	170	—	171	—
$\rho_e \rightarrow 0.8\rho_e$	171	1.0 %	174	1.9 %
$\theta_s \rightarrow \theta_s$+5°	173	1.8 %	171	0.4 %
$r \rightarrow 1.5r$	236	39 %	183	7.1 %

Note that the size of the room has the greatest effect on the ambient-contrast result as anticipated. The wall reflectance has a lesser, but nontrivial, effect. The angular placement of the lamp is more important for the LCD than for the PDP, which would also be expected from the quasi-Lambertian behavior of the PDP. To fix this kind of a room measurement to make it robust would require exact specification of its size and wall reflectances. It is unlikely that making such requirements in a standard would be well received. Note that this model does not take into account the shape of a rectangular room, nor does it account for such objects in the room as the operator, the luminance meter, a tripod, etc. Such objects will further increase the uncertainty of the measurement as would a tiled floor having a more specular-like component of reflection than would a diffuse wall. The results in Table 1 may therefore be regarded as lower bounds.

4. Robust Room Measurements

Establishing the contrast of a display for a certain type of room is a very reasonable goal to achieve, provided that the measurement method is robust. We have seen that an ill-defined room will not provide a robust measurement of the reflection properties of any type of display. This does not mean that robust measurements cannot be made to simulate the reflection performance of the display in a room. Unfortunately, space does not permit a full discussion of the details of properly making ambient-contrast measurements using directed and uniform diffuse sources. The reader is referred to the references for those details.

We can use the illumination from a directed source in a darkroom to simulate the lamp in the ceiling. Provided that the angle between the normal of the screen and the directed source is sufficiently correct and the source diameter is sufficiently small, this can be a robust measurement using a directed source, especially at large angels from the normal.[3] Uniform diffuse ambient illumination can be provided by an integrating sphere or a sampling sphere that is placed upon or very near the display surface. [4] Such diffuse-reflectance measurements are well known to be very robust, and the use of a sampling sphere is also not new. [5]

It may be possible to combine the directed source with the diffuse source so that robust ambient contrast measurements can be obtained by scaling the results to design ambient conditions with a single apparatus and making only two measurements on the display under illumination conditions. Research is underway to test such a method either with the display inside an integrating sphere or by use of a sampling sphere. A design uniform-diffuse illuminance and a design directed-source illuminance must both be specified as by a standards committee. The illuminance from the diffuse source used in the measurement will be adjusted to be in the same ratio to the directed source as that of the design illuminances. The resulting measured luminances would then be scaled to the design levels to calculate the ambient contrast.

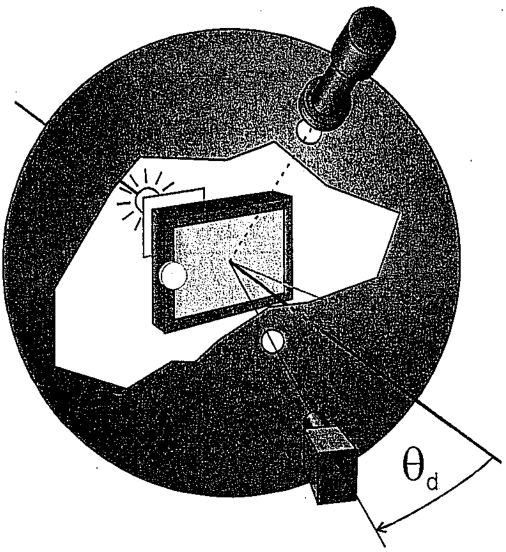

Figure 4. Combined ambient-contrast measurement where the illuminance E_d from the uniform source is adjusted to give the correct ratio with E_s from the directed source. The results are then scaled to the design illuminance conditions. (This method is currently being researched.)

5. Terminology

The term "bright-room" is being used where the illuminance E_n is specified to be 100 lx. Few would call such a room bright. This is especially true if the walls are dark with reflectances of only 10 % or less—such rooms are approaching darkroom wall reflectances of 5 % or less. Office illuminance levels have been characterized: The illuminance associated with a vertical plane in a normal office is 250 lx. [6] Many offices exceed this illuminance level and have very light walls. Terminology is important, and new metrics should have well-though-out names that properly describe what they are to avoid confusion. Therefore, it might be prudent if another term were used such as "viewing-room contrast," "entertainment-room contrast," "living-room contrast" or something other than "bright-room contrast." To capture the term "bright-room" for such a *dim* room leaves few remaining adjectives in terminology should we need to develop an ambient-contrast metric for truly bright rooms such as are encountered in a well illuminated building lobby with many windows, a well-lit laboratory, a well-lit hallway, or an operating room. Metrology has as much to do with integrity as it does with good measurement methods.

6. Conclusion

Our simplified model demonstrates that a room-based measurement of the display under reflections is not a reasonable configuration to use if reproducibility is desired by the display industry. The concept of making ambient-contrast measurements is certainly valid, but care must be taken to assure that the measurement result is not unduly influenced by configuration changes that would be anticipated to occur from laboratory to laboratory. Ambient-contrast measurements can be made on displays by use of robust apparatus such as integrating spheres and directed light sources, perhaps even in combination. If such robust measurement methods are selected by standards organizations, then their main concern will be to establish the appropriate levels of illuminance for their anticipated room conditions. It is strongly encouraged that robust arrangements be implemented by standards organizations before a bad measurement method is introduced under which the industry and display users would suffer for a long time.

7. References

[1] The idea of distinguishing three components of reflection (Lambertian, specular, and haze) is explained in: E. F. Kelley, G. R. Jones, and T. A. Germer, "The Three Components of Reflection," Information Display, Vol. 14, No. 10, pp. 24-29, October 1998. For more details as to how these relate to the BRDF, see: E. F. Kelley, G. R. Jones, and T. A. Germer, "Display Reflectance Model Based on the BRDF," Displays, Vol. 19, No. 1, pp. 27-34, June 30, 1998. Both are available from our web site <www.fpd.nist.gov> via the Reflection Metrology link (2006).

[2] Flat Panel Display Measurements, Video Electronics Standards Association (VESA), FPDM, Version 2, Section A212, p. 264, June 1, 2001 (www.vesa.org). The exit port area of the spherical room is set to zero in our calculation.

[3] E. F. Kelley, M. Lindfors, and J. Penczek, "Display Daylight Ambient Contrast Measurement Methods and Daylight Readability," J. Society of Information Display, Vol. 14, No. 11, pp. 1019-1030, November 2006. See: www.fpd.nist.gov under the Reflection Metrology link.

[4] E. F. Kelley, "Diffuse Reflectance and Ambient Contrast Measurements Using a Sampling Sphere," Proceedings of the Third Americas Display Engineering and Applications Conference (ADEAC 2006), Society for Information Display, Atlanta, GA, USA, pp. 1-5, October 24,26, 2006. See: www.fpd.nist.gov under the Reflection Metrology link. This is a preliminary report, and modifications to these ideas are planned for a future archival publication.

[5] See, for example, CIE Publication No. 44, *Absolute Methods for Reflection Measurement*, Commission Internationale de l'Eclairage (International Commission on Illumination), 1979 reprinted 1990. For the use of a sampling sphere see the Sharp-Little method (Fig. 10).

[6] ISO 13406-2:2001, Section 7.3, "Ergonomic requirements for work with visual displays based on flat panels -- Part 2: Ergonomic requirements for flat panel displays," International Organization for Standardization, 2001. See also ISO 9241-3:1992, "Ergonomic requirements for office work with visual display terminals (VDTs): Visual display requirements," International Organization for Standardization, 1992.