Robustness of Display Hemispherical Reflectance Measurement Apparatus

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Keywords : diffuse reflectance, integrating sphere, display reflection measurements

Abstract

Reflection measurements are critical to the evaluation of display performance under ambient illumination conditions. Various hemispherical reflection methods are evaluated for their suitability and robustness across display technologies. The standard integrating sphere method is compared to a sampling sphere apparatus.

1. Introduction

From the blue sky illumination on a cell phone to the reflected light from office walls onto a desktop monitor, most practical illumination geometries contain a diffuse background. In the case of displays used in daylight conditions, the skylight and surround illumination can create reflections that dominate over the direct sunlight or the images presented on the display. It is therefore important to characterize the performance of the display under uniform diffuse illumination, more properly called hemispherical illumination. (In this discussion we are referring to photometric and not radiometric measurements of reflection properties.) For example, the hemispherical reflectance can be used to calculate the display contrast ratio under hemispherical illumination. [1] Previous work has demonstrated that display reflection measurements performed under hemispherical illumination (using integrating spheres) tend to be insensitive to small changes in the apparatus parameters. [2] The comparative ease with which the data can be reproduced makes this method quite robust. Although hemispherical reflectance measurements have traditionally been performed with the display placed inside an integrating sphere or hemisphere, this can be impractical for large displays. Hemispherical illumination can be obtained in a variety of apparatus in addition to the integrating sphere. [3, 4] This paper explores the display size limitation of reflection measurements in integrating spheres, and the prospect of using a sampling sphere to overcome those limitations.

2. Experimental

The robustness of hemispherical reflectance measurements using integrating spheres was investigated by using three differently sized integrating spheres: (1) a large 1.9 m diameter sphere, (2) a 90 cm diameter sphere, and (3) a 61 cm diameter sphere. All have interior walls coated with barium sulfate. The largest sphere employed a tungsten-halogen source at approximately 2856 K. The two smaller spheres used a cluster of bluish-white light-emitting diodes (LEDs). The display or test sample was placed at the center of the integrating sphere. Reflection measurements were performed with a detector angle of $\theta_d = 10°$ from the normal of the sample (see Fig. 1). A baffle was arranged so that no direct ray from the lamp (tungsten or LED) struck the front hemisphere. The 61 cm diameter sphere had a measurement port of 50 mm in diameter. The diameter of the measurement port of the 90 cm sphere could be changed from 57 mm to 31 mm by use of an insert. The largest sphere had an adjustable iris (58 mm to 2 mm) for the measurement port. A luminance meter was used as the detector. It was focused on the sample, and the room lights were turned off to avoid veiling-glare contributions from areas surrounding the measurement port. A white diffuse reflection reference with known hemispherical reflectance ρ_{ref} was placed adjacent to the sample. The hemispherical reflectance ρ of the sample could be determined by comparing the

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luminance of the white reflectance reference L_{ref} to the luminance of the sample L:

$$\rho = \rho_{ref} \frac{L}{L_{ref}} \quad (1)$$

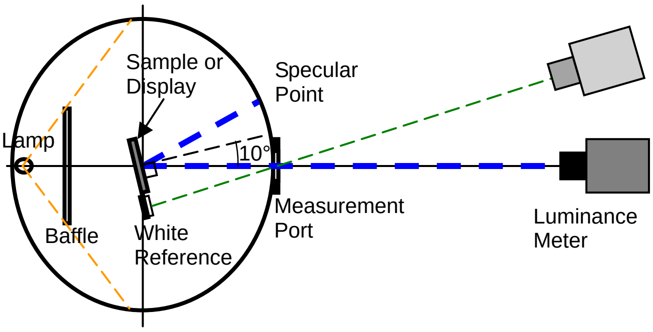

Fig. 1. Integrating-sphere configuration used for hemispherical reflectance measurements—top view.

A 30 cm diameter sampling sphere was investigated as an alternate means for measuring display hemispherical reflectance. A fiber optic light guide illuminates the sphere's interior with light from a white tungsten source (see Fig. 2). Test samples were placed against the sphere's 75 mm sample port, and their luminance were measured by a luminance meter through a measurement port at 10° from the sphere's axis of symmetry. A white diffuse reflection reference was mounted adjacent to the sample port, flush with the sphere wall, following the Sharp-Little method. [5] The white reference was previously calibrated relative to the known illuminance at the sample port to determine its hemispherical reflectance for this illumination geometry. The hemispherical reflectance of the sample was measured following the same process as in equation (1).

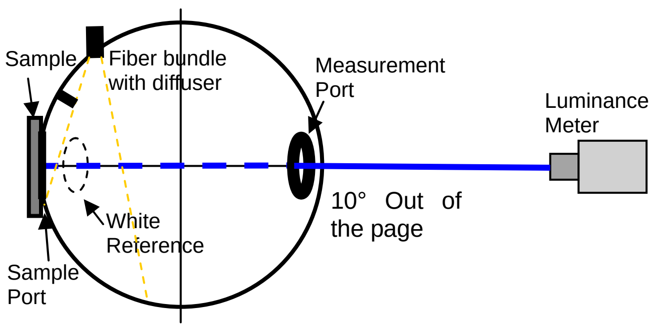

Fig. 2. Side view schematic of sampling sphere following the Sharp-Little method. Test sample was placed against the sample port and its luminance was compared to a white reference in the same horizontal plane.

The hemispherical reflectance of 75 mm square reflection samples were measured relative to a white sample with a matte surface (quasi-Lambertian) as a reference. A variety of scattering surfaces were measured. The impact of measuring displays of various size inside an integrating sphere was simulated by placing a black insert directly behind the test samples. The square dimensions of the black inserts ranged in size from 5 cm to 38 cm on a side.

3. Results and discussion

The relative hemispherical reflectance of a glossy black sample measured with the various size spheres is shown in Fig. 3. The relative uncertainty at the 95 % confidence level is estimated to be 1 % for all the hemispherical reflection measurements, based on modeling results and measurement repeatability. As expected, the curve for each integrating sphere is relatively flat for small black inserts. However, as the insert size was increased, it created a shadow on the front of the sphere. The induced sphere lighting nonuniformity affects the illumination distribution on the sample. The bidirectional reflectance distribution function (BRDF) is a measure of the luminance sensitivity to the illuminance distribution. It is known that the glossy black sample has a BRDF that is highly sensitive in the specular direction. In contrast, the white sample will have a more moderate sensitivity over a broader range of incident angles. Since the black sample's hemispherical reflectance was referenced to that of the white sample, the mismatch in the BRDF of the two samples should lead to a variation in the reflectance data with increasing nonuniformity of the sphere illuminance.

A reflection measurement of the glossy black sample was also taken with the sampling sphere and is shown in Fig. 3. The sampling sphere reflection measurement is lower by up to 1.5 % relative to the large integrating sphere reflectance values based on the small inserts. Better agreement is expected with more uniform light source illumination. This initial result demonstrates the potential of using a sampling sphere as a means to alleviate display or fixture shadowing in integrating spheres.

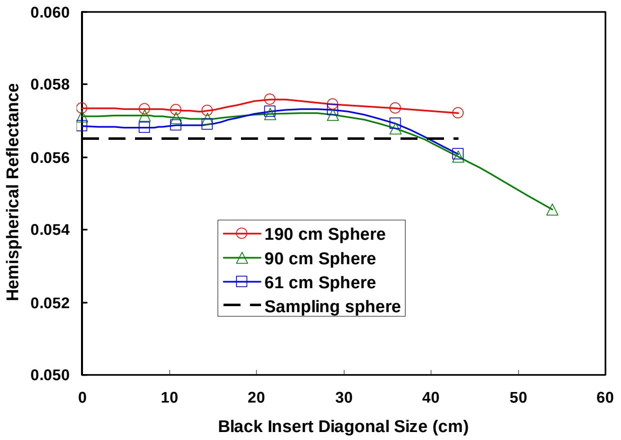

Fig. 3. Hemispherical reflectance of a glossy black sample as a function of black insert size. The black insert was placed behind the glossy black sample to simulate the effect of display size on reflectance measurements. The sample reflectance was measured with integrating spheres of three different sizes, and a sampling sphere. The overall expanded uncertainty for the integrating sphere measurements is estimated to be 1 %, and 3 % for the sampling sphere.

Table 1 lists the hemispherical reflectance of several reflection samples that were used to simulate various displays without the black inserts. The H1 and H2 samples have only a haze reflection property, the BG sample is a glossy black glass with a strong specular component, and the SHL sample has all three reflection components: specular, haze, and Lambertian. The results indicate that the sampling sphere is within 2 % of the integrating sphere data for the various samples. Further design improvements to the sampling sphere should substantially reduce this difference. The good correspondence between the differently size spheres and sampling sphere demonstrates the robustness of this method to variations in the sample scattering properties.

4. Summary

We have investigated the impact of display size on hemispherical reflectance measurements with integrating spheres. Our data agrees with the conventional wisdom that the diagonal display size needs to be less than 1/7 the diameter of the sphere in order to achieve good results. This would have significant cost and space implications when trying to measure large displays. However, we have demonstrated that a sampling sphere can provide a cost effective alternative that can be applied to a wide range of display sizes and scattering properties.

5. References

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[5] 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).

Table 1. Hemispherical reflectances measured by different integrating spheres.

Sample Name	1.9 m (tungsten-halogen)	90 cm (LED)	61 cm (LED)	Integrating Sphere Average	30 cm Sampling Sphere	Sampling Sphere Deviation (%)
H1	0.04496	0.04500	0.04502	0.0450	0.0442	-1.9
H2	0.04792	0.04794	0.04787	0.0479	0.0470	-1.8
BG	0.04209	0.04219	0.04222	0.0422	0.0414	-1.8
SHL	0.1154	0.1155	0.1153	0.115	0.113	-2.0