Reflection Measurement Problems Arising from Haze

George R. Jones, and Edward F. Kelley*

NIST, Gaithersburg, MD

Abstract

Irreproducibility in some reflection measurement methods arises from the observance of the haze component of reflection (non-regular-specular, non-Lambertian). Because of the haze component, the measured reflection is sensitive to the apparatus configuration. We show the effects of detector lens aperture and detector distance on the measurement of the reflected luminance. Only for detectors with small subtense angles can reproducibility be assured when haze reflection is nontrivial.

Introduction

In the development of display standards researchers have encountered difficulties in specifying adequate reflection metrology because of a lack of reproducibility using existing measurement techniques. Regular specular and Lambertian diffuse reflection models have been employed to design some of the measurements. By employing a more complicated model of reflection we are able to explain and modify our measurements to avoid some of the anomalies.

In previous work we have introduced a three-component reflection model based on the bidirectional reflectance distribution function (BRDF). [1,2] The BRDF relates the observed luminance to the illuminance:

$$dL_{\mathrm{r}}(q_{\mathrm{r}}, f_{\mathrm{r}}) = B(q_{\mathrm{i}}, f_{\mathrm{i}}, q_{\mathrm{r}}, f_{\mathrm{r}})\, dE_{\mathrm{i}}(q_{\mathrm{i}}, f_{\mathrm{i}}), \qquad (1)$$

and the BRDF comprises a linear sum of the three components: specular (S, mirror like), diffuse (D, Lambertian), and what we will call haze (H, for want of a better term):

$$B = D + S + H\,. \qquad (2)$$

Because the front surface of the display can be placed relatively close to the pixel surface, flat panel displays (FPDs) can be made so that they have only a nontrivial haze component, i.e., D ≈ 0 and S ≈ 0. The reflection of the haze component can be further reduced by multilayer antireflection coatings. It is the haze reflection component that causes the complications in reflection measurements of displays. The measurement of haze depends upon the apparatus configuration: the distances of the source and detector, the aperture of the detector, the focus of the detector, etc. Only if the subtense angle of the detector is small can reproducible measurements of haze be made.

Stover has demonstrated that the measurements of the peak of the BRDF near specular can be reduced by several orders of magnitude as the aperture of the measuring optics is increased.[3] The width of the peak increases as the aperture increases. The combined effect is to flatten and broaden the specular peak as the aperture is increased.

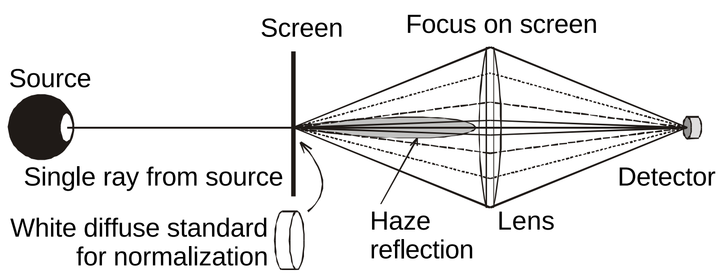

Fig. 1. *Unfolded specular configuration showing the haze reflection of a single ray into a variable aperture lens.*

Results

The luminance from a sample illuminated with a single ray from a light source is shown in Fig. 1. The light path is shown in an unfolded configuration for simplicity. The haze reflection for a single ray is shown as a lobe with an exaggerated width for illustration purposes. The detector is a charge-coupled device (CCD) with a 90 mm lens having apertures from 2.8 mm (f/32) to 32.1 mm (f/2.8). A point light source is placed 820 mm from the sample for illumination. Fig. 2 shows the resulting data. At 1000 mm from the sample surface the detector lens subtends only the peak region of the lobe since the collection solid angle ranges from 0.8 msr (f/2.8) to 0.006 msr (f/32). These data show an insensitivity to lens aperture. However, at a distance of 200 mm the collector solid angle ranges from 0.16 (f/32) to 20 msr (f/2.8). At f/32 the lens measures only the peak luminance value of the lobe. At larger apertures, the lens averages over an increasingly larger percentage of the haze lobe whereby the average value of the luminance decreases

* *Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce.*

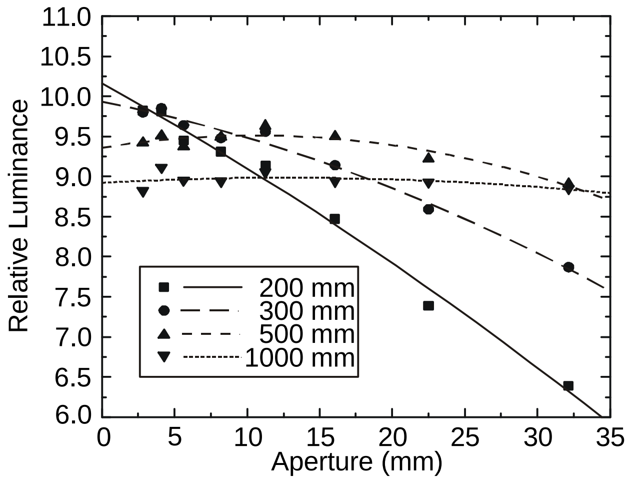

Fig. 2. *Reflected luminance relative to a white standard of a haze sample as a function of aperture and distance*

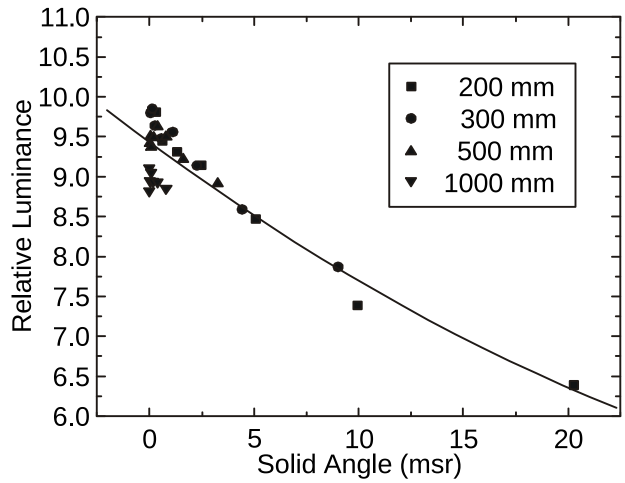

Fig. 3. *Reflected luminance relative to a white standard of a haze sample as a function of collector solid angle and distance*

with aperture increase—a 40 % change in measured luminance.

After each measurement of the haze reflection, the sample is replaced by a white standard to normalize the data against a Lambertian reflector. The curves in Fig. 2 are second order polynomials fit through each individual data set. The effect of distance and aperture on measured luminance is better illustrated in Fig. 3, which plots all of the data versus the collector solid angle, or subtense angle in Fig. 4. Similar problems arise when the focus of the detector lens is changed, i.e. whether the system is focused on the surface of the sample or on the light source.

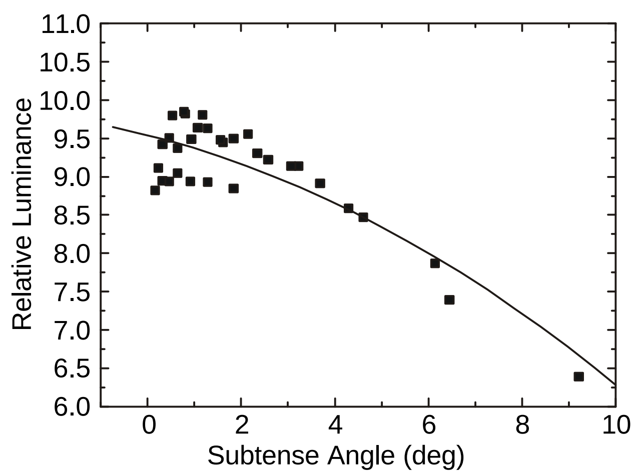

Fig. 4. *Reflected luminance relative to a white standard of a haze sample as a function of subtense angle and distance*

---

[1] G. Jones, E. Kelley, T. Germer, "Specular and Diffuse Reflection Measurements of Electronic Displays," Society for Information Display International Symposium Digest of Technical Papers, Vol. 27, San Diego, CA, pp. 203-206, May 12-17, 1996.

[2] E. F. Kelley and G. R. Jones "Utilizing the Bidirectional Reflection [should be Reflectance] Distribution Function to Predict Reflections from FPDs," Society for Information Display International Symposium Digest of Technical Papers, Vol. 28, Boston, MA, May 12-15, 1997, pp 831-834.

[3] John C Stover, *Optical Scattering, Measurement and Analysis*, SPIE Optical Engineering Press, pp.139-143, 1995.