24.1: Character Contrast Under Uniform Ambient Conditions

Edward F. Kelley*, John Penczek, and Paul A. Boynton
NIST, Boulder, Colorado, U.S.A.

Abstract

The measurement of small-area black regions (such as a character stroke) on a white screen can be subject to large errors because of veiling glare in the detector. By using replica masks we can enable more accurate measurements of small-area-black and character contrasts even under ambient illumination.

1. Introduction

The accurate measurement of the luminance of a small black area such as a character stroke amidst a white screen can be one of the most difficult measurements to perform. The problem is veiling glare in the detector from the bright areas corrupting the luminance of the small dark area. Our concern is with the measurement rather than how well the eye can see the contrast; vision models can be applied after a careful measurement result is obtained. [1] Often array detectors (cameras) such as charge-coupled-devices (CCDs) or complementary-metal-oxide-semiconductor (CMOS) cameras are employed, and errors in our making the luminance measurement of the small black area can be in excess of 1000 % because of veiling glare. [2]

The use of replica masks has been demonstrated to be a successful method to determine the luminance of small black regions for emissive displays in a darkroom. [3] For this darkroom situation, the replica is the same size as the black region being measured and is opaque, so that it provides a direct indication of the veiling-glare correction needed. However, in an ambient illumination situation, we must account for the reflectance of the replica in addition to the veiling-glare corruption that it manifests. This paper presents a method to obtain small-area black measurements under uniform ambient illumination conditions with the use of replica masks.

2. Method

Figure 1 shows a display placed in an integrating sphere that bathes it in a uniform ambient illumination. The display is rotated $8° \leq \theta \leq 10°$ so that its normal is not aligned with the center of the measurement port. Note that for the sake of the drawing size, the sphere is smaller than it should be. Generally we want the diameter of the sphere to be approximately seven times the diameter of the object being measured, or use a sampling sphere. The top part of Fig. 1 shows the display with a replica cut to be the same size as a large capital letter "I" (sans serif). A large piece of opaque black material from which the replica is made is placed at the right (we refer to this sample as the replica material). A white reflectance standard is placed at the left to provide a measurement of the illuminance. The illuminance is assumed to be uniform across the display. An array detector is pivoted about the measurement port to measure the luminance of the standard, the center of the display, and the black replica material.

Figure 2 shows the images obtained by the array detector. Note that the disk of the black replica material needs to be large enough

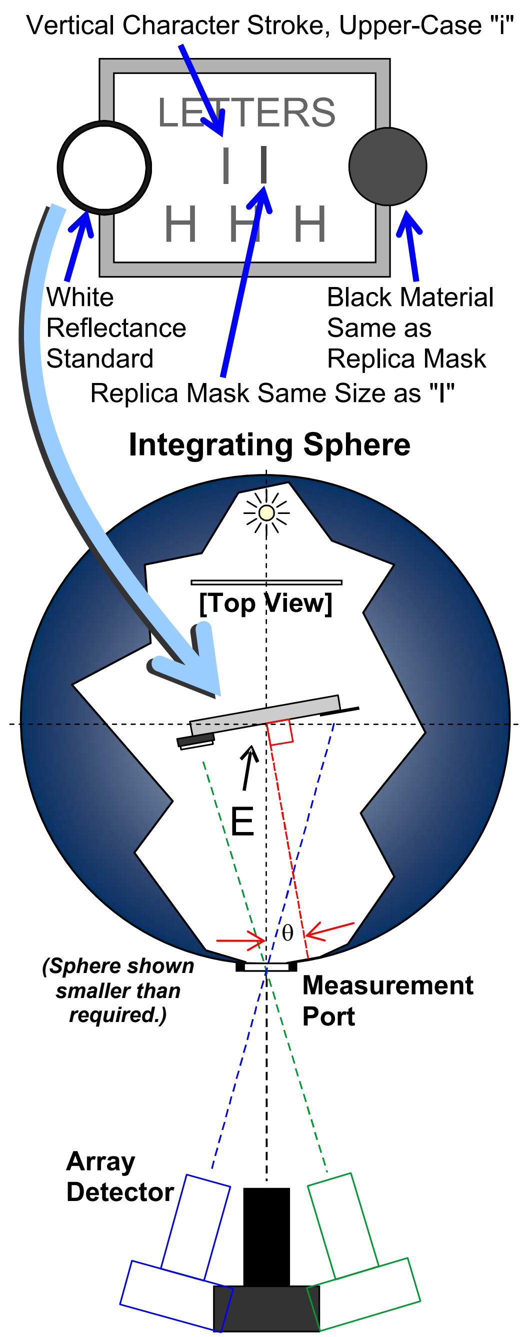

Figure 1. Uniform diffuse ambient illumination to make small-area luminance or character-contrast measurements with an array detector.

---

and the detector needs to be moved back away from the measurement port enough so that when the replica luminance L_M is measured, there is no contamination from any bright area within the integrating sphere.

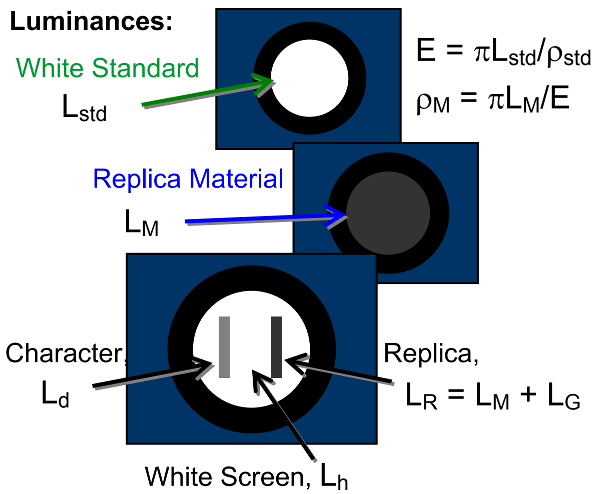

Figure 2. Array-detector images.

Additionally, the measurement port is out of focus, because it is not in the focal plane of the display surface. Figure 3 shows a wide-angle view of the out-of-focus measurement port with the white screen of a reflective display in view. Therefore, the region of the vignette that surrounds the interior of the measurement port must be avoided. Only the uniform interior region of the measurement-port image can be employed to make luminance measurements. This uniform region within the vignette is illustrated in Fig. 4, which shows the average vertical cross section of the white box in the image in Fig. 3. Measurements are generally made by our using higher magnification (a lens of longer focal length) than shown in Fig. 3; so the entire image is within the uniform region within the vignette region.

The luminance L_{std} of the white reflectance standard provides the illuminance E from the calibrated reflectance of the standard ρ_{std}:

$$E = \pi L_{std}/\rho_{std} \, . \tag{1}$$

(Note that ρ_{std} must be calibrated for the illumination condition under which it is used, in this case uniform hemispherical illumination—these white reflectance standards are not Lambertian.) The reflectance ρ_M of the replica material is obtained from its luminance L_M by our carefully avoiding any glare from surrounding bright regions:

$$\rho_M = \pi L_M/E \, . \tag{2}$$

The luminance L_R of the replica is measured (by our avoiding any vignette), and the amount of glare luminance L_G on the replica is then given by

$$L_G = L_R - L_M \, . \tag{3}$$

We might be tempted to assume that the white luminance L_h has this glare added to it. However, in the limit of an infinitely narrow black line, the glare will be essentially equal to the white area luminance. Our subtracting such a glare from the white luminance will yield white values that are entirely too low Thus, we will assume, unless we make direct measurements otherwise, that the white luminance L_W with the ambient reflections included is not affected by this glare:

$$L_W \cong L_h, \tag{4}$$

However, this glare luminance is certainly added to the small area or character stroke. The corrected value for the black luminance L_K of the small area is

$$L_K = L_d - L_G, \tag{5}$$

whereby the ambient character contrast C_{CA} is

$$C_{CA} = L_W/L_K. \tag{6}$$

This contrast is peculiar to only the level of uniform illuminance E used to make the measurements. To make these measurements more useful, it makes sense to make them scalable to any desired level of illuminance E_0. In order to do this, we need to take the extra steps to determine the corrected hemispherical reflectances for the white screen, ρ_W, and the small-area black, ρ_K.

Suppose the darkroom luminances of the white screen, L'_W, and the small black area, L'_K, are available to us. Let primes denote the darkroom measurements that use the same replica configuration.

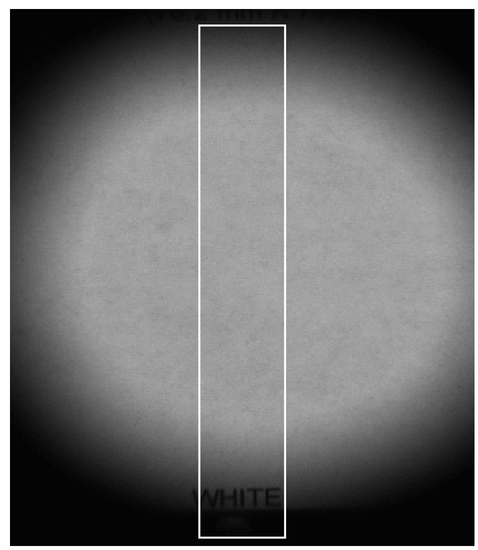

Figure 3. Vignette from measurement port.

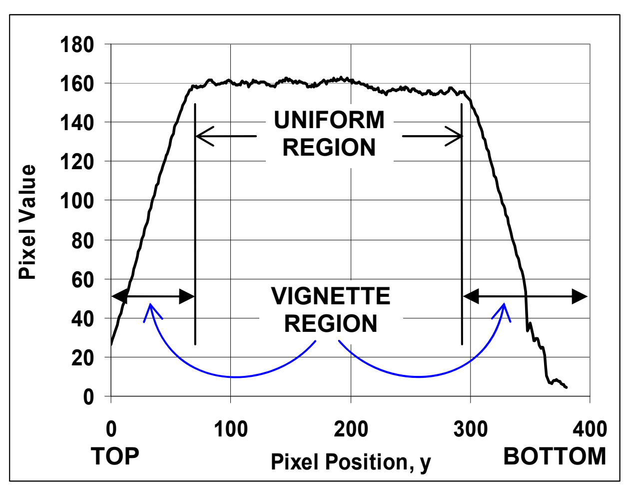

Figure 4. Uniform region within vignette.

For a reflective display this extra step would not be necessary, because there are no emissions from a purely reflective display, $L'_K = L'_W = 0$. For an emissive display, we would use the same procedure as above only without the surround, but we would measure the same place on the screen and from the same angle from the normal used with the surround. Because there is no illumination, $E' = 0$, then the luminance of the replica material is zero, $L'_M = 0$, and the glare luminance is simply the replica luminance L'_R. By our assuming that the white luminance is not being corrupted by the glare, we have

$$L'_W \cong L'_h . \quad (7)$$

The dark luminance is corrected for the glare:

$$L'_K = L'_d - L'_R. \quad (8)$$

We now have the emission properties of the display for the measured regions. These can be subtracted from the luminances measured under uniform illumination (with the surround) to determine the net reflected luminances and the resulting

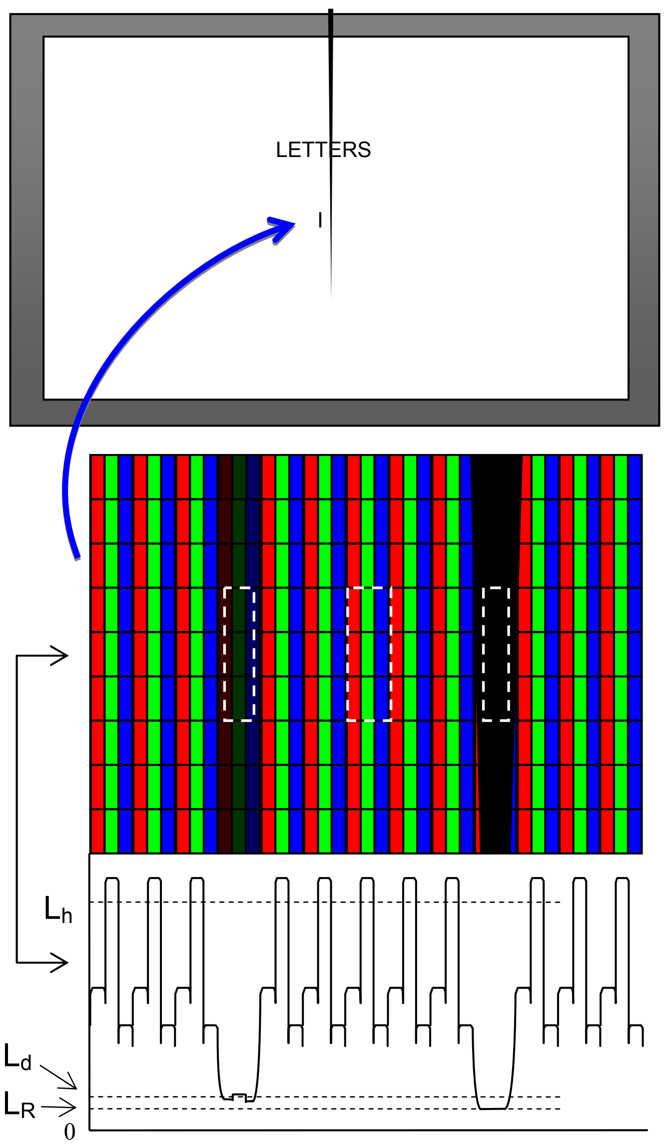

Figure 5. Narrow-taper replica mask usage.

reflectances of the white screen, ρ_W, and the small black area, ρ_K:

$$\rho_W = \pi(L_W - L'_W)/E, \quad (9)$$

and

$$\rho_K = \pi(L_K - L'_K)/E. \quad (10)$$

Note that for a purely reflective display L'_W and L'_K are both zero.

For any illuminance E_0, the ambient character contrast or small-area contrast is given by

$$C_{CA} = \frac{L'_W + \frac{\rho_W E_0}{\pi}}{L'_K + \frac{\rho_K E_0}{\pi}} . \quad (11)$$

Again, for purely reflective displays, $L'_K = L'_W = 0$, and the ambient character contrast simplifies to the ratio of the reflectances:

$$C_{CA} = \rho_W/\rho_K \quad \text{[reflective displays]}. \quad (12)$$

When implementing the replica-mask method, it can be troublesome to try to cut a replica for very small areas and most characters used for text. A very narrow-tapered replica can be cut from the opaque replica material with a razor blade and then used to simulate the character stroke, particularly for longer strokes. Figure 5 shows the use of a narrow-tapered replica for a one-pixel wide black line. The narrower measurement boxes in the dark areas avoid the localized glare from the adjacent bright areas.

The above replica-mask method provides a better measure of the small-area or character-stroke luminance and contrast than would be obtained if we didn't account for veiling glare. Even so, it yields only an approximation, because it is a simplification of the problem. The contribution of glare is uniform neither locally from the edge of the character stroke or small area, nor is it expected to be uniform across the measurement port area that is within the non-vignetted region. However, as will generally be observed, the values for the contrasts obtained are much closer to the "true" values than would be obtained if we made no attempt to account for veiling glare.

3. Results

A reflective grayscale display is measured within a 1.9 m diameter integrating sphere. The white reflectance standard is assumed to have a reflectance of $\rho_{std} = 0.98$, whereby the reflectance of the replica-mask material is determined to be

$$\rho_M = \rho_{std}\, L_M/L_{std} = 0.0418, \quad (13)$$

as measured by a luminance meter. (All absolute or relative luminance measurements in this report are estimated to have a relative expanded uncertainty with a coverage factor of two of 5 %). The luminance of the white standard is $L_{std} = 1475$ cd/m^2, which indicates an illuminance of $E = \pi L_{std}/\rho_{std} = 4728$ lx. The array detector is a 16-bit photopic camera with a 300 mm focal-length lens set at f/32 (exposure of 1.8 s) placed approximately 1 m away from the measurement port and focused on the surface of the display. The camera employs background subtraction and flat-field corrections. We find a slight additional background with the lens cap on that is not accounted for automatically and must be subtracted manually. The measurement-port iris is set at a 33 mm diameter to reduce stray light from the surrounding bright interior of the integrating sphere as much as possible without the port producing too large a vignette. The display with white standard and replica material is rotated about a vertical axis so that the normal of the display surface is 10° to the right of the center of the measurement port. It would have been better to have a longer lens to provide more magnification. As it was, we were able to get only approximately six detector pixels for every display pixel. A better ratio would be 10:1 or even 20:1 detector pixels to display pixel. For the narrower lines we used the rather well defined minimum of the profile. For the wider lines (10 px and wider) we used an average reading within a measurement box near the central minimum of the line profile. Figure 6 shows the tapered matte-black-plastic masks and the stepped-line pattern on the display of widths of 30, 20, 15, 10, 5, 4, 3, 2, and 1 pixels.

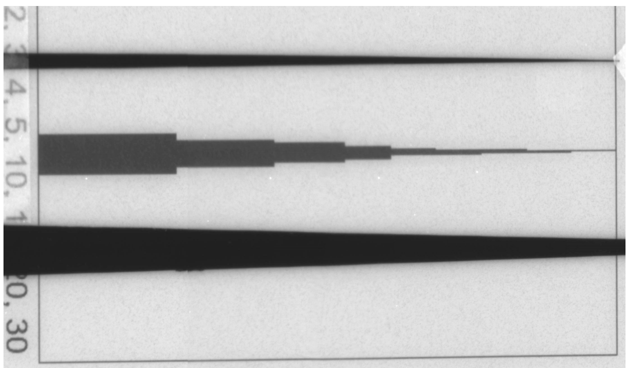

Figure 6. Image of display screen with tapered

Figure 7 shows the ambient contrast as a function of line width for the pattern in Fig. 6. The lower data is the contrast that would be obtained without a veiling-glare correction, as would be obtained if we simply accepted the readings from the camera. Without correction, we would be led to believe that the contrast of the display decreases as the line width decreases. However, when a veiling-glare correction is attempted, the ambient contrast is observed not to change appreciably, as seen in the upper data. If we consider the measurement of the reflectances based upon the corrected data we find a remarkably constant reflectance independent of line width:

$$\rho_W = \pi L_W / E = 0.450 \pm 2\ \%, \qquad (14)$$

$$\rho_K = \pi L_K / E = 0.124 \pm 2\ \%. \qquad (15)$$

For this reflective display, the ratio of the reflectances is the ambient character contrast of the display, in this case 3.6 ± 3 %, under any level of ambient light.

Earlier, in Eq. 7 and the discussion above it, we argued that the glare contribution for the white luminance could be neglected. Figure 8 shows the glare contribution as a percentage of the white screen luminance. For our optical configuration, it would appear that the overall veiling-glare contribution to white is less than 2 %. If higher accuracy contrast measurements are needed, this kind of analysis would be required to make a glare correction to the white level.

We employed a reflective display in this example. Had we used an emissive display, then darkroom measurements using replicas would have been necessary, as explained in the previous section. It is important to point out that for emissive-display measurements the detector should be sufficiently far away from the screen that the bright screen reflections from the detector do not affect the measurement results by illuminating the replica masks.

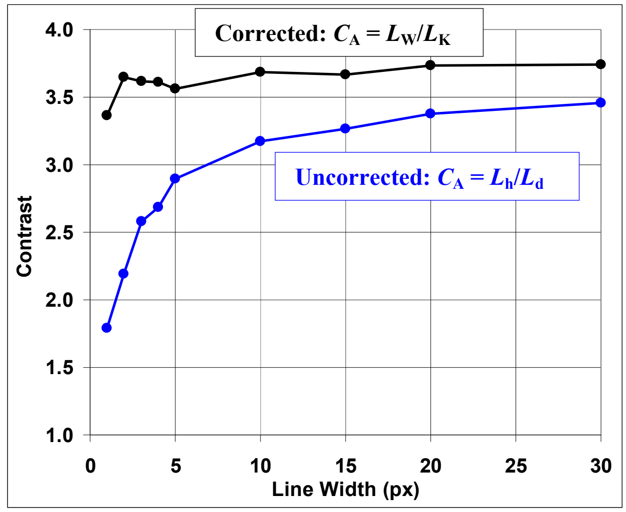

Figure 7. Contrasts vs. line width with and without correction for veiling glare.

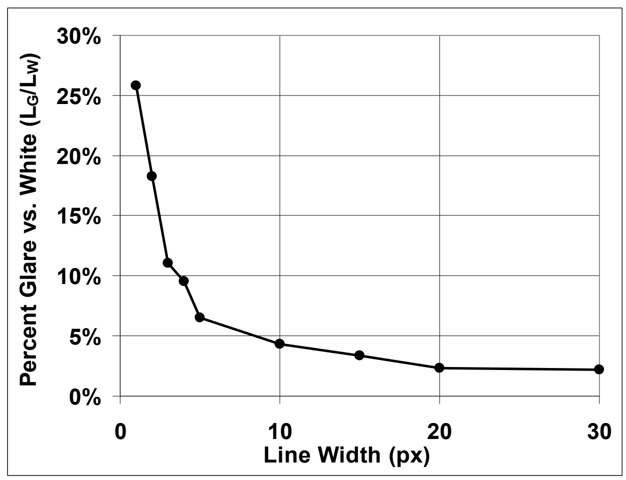

Figure 8. Glare contribution vs. white screen.

4. References

[1] T. G. Fiske and L. D. Silverstein, "Estimating Display Modulation by 2-D Fourier Transform: A Preferred Method," Journal of the Society of Information Display, Vol. 14, No. 1, pp. 101-105, January 2006.

[2] J. W. Roberts and E. F. Kelley, "Measurements of Static Noise in Display Images," Proceedings of the SPIE V4295B-27, Electronic Imaging Symposium, San Jose, CA, pp. 211-218, January 23, 2001.

[3] P. A. Boynton and E. F. Kelley, "Small-Area Black Luminance Measurements on a White Screen Using Replica Masks," 1998-SID International Symposium Digest of Technical Papers, Society for Information Display, Vol. 29, pp. 941-944, Anaheim, CA, May 17-22, 1998.