32.1: Accurate Contrast Ratio Measurements Using a Cone Mask

P. A. Boynton and E. F. Kelley

NIST, Gaithersburg, MD*

Abstract

Display contrast ratios are often derived from luminance measurements of black and white patterns. Erroneous contrasts are obtained if veiling glare contributions of the optical system are not considered. We present a method for avoiding glare corruption of luminance measurements utilizing a glossy black cone-shaped mask.

Introduction

Many electronic display users, manufacturers, and standards include determining the contrast ratio of a display as part of an evaluation of its quality. The contrast ratio (C_R) metric can be defined as the ratio between the luminance of the white areas of a display screen L_w, and the luminance of the dark areas L_b:

$$C_R = \frac{L_w}{L_b} \ . \qquad (1)$$

Unfortunately, conventional methods employed for measuring the C_R can provide inaccurate data. Errors result from the contributions of light scattered by the optical system of the measuring instrumentation—including reflections between lens surfaces, barrels, irises, and defects in the glass. This scattering effect is often called veiling glare (sometimes referred to as surround effect or lens flare) and is well understood and characterized in the optics field [1]. However, the concept has only recently been introduced into the display standards arena [2].

Veiling Glare

As previously mentioned, veiling glare due to scattering can produce misleading results in C_R measurements. Figure 1 shows a typical C_R test pattern used in some display standards. The circle within the square represent the measurement aperture of a light-measuring device (LMD). Surrounding areas of luminance, if not masked, can corrupt the measurement. This error, called flare factor, is defined as:

$$flare\ factor = \frac{L_g}{L_t - L_g}, \qquad (2)$$

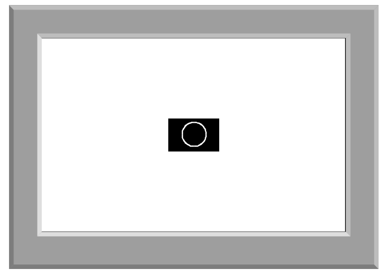

Fig. 1. Typical contrast ratio measurement

where L_t is the total measured luminance, and L_g is the contribution due to the veiling glare. Reference [1] describes one method for calculating flare factor. Keep in mind, a different flare factor will occur for different light sources and different orientations of the source with respect to the LMD.

Flat Masks

One method for reducing the glare effects involves using flat masks to shield areas of the display so that most of the light outside of the measurement area is rejected (see Fig. 2a), These masks may be constructed out of glossy black material, matte black material, black felt, or black flocked paper. Care is needed in using these masks, since placement of the mask on the surface of the display can damage delicate surfaces, or affect the properties of the display (such as through warming). Some masks may damage the surface of an expensive prototype display, or for other reasons may not be able to be placed directly on the display surface (such as a covering glass on the display surface, or other measurement system restrictions). To avoid some of these limitations, a cone mask was developed.

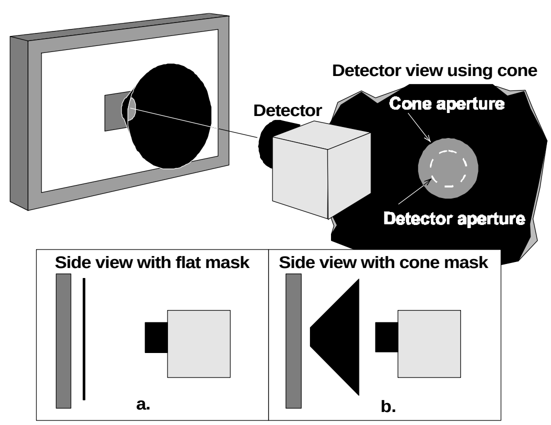

Fig. 2 Masks

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

An evaluation of the cone mask and a comparison with various flat masks is presented.

Cone Masks

A gloss black cone mask can be used to restrict much of the unwanted light from entering the LMD (see Fig. 2b). To avoid light from the rest of the display being reflected onto the viewing area and to avoid the light from other parts of the screen reflecting off the interior of the cone and into the lens, the apex angle of the cone should be 90° (45° each side of the optical axis of the LMD and the symmetry axis of the cone). To prevent the edge surface of the cone from obscuring any of the measured area (producing a vignette), the cone must be placed close enough to the display surface so that the inequality shown in Fig. 3 is satisfied:

$$a < a_{\max} = d\frac{(s-u)}{(w-u)}, \qquad (3)$$

where a the distance of the edge of the aperture of the cone from the display surface, u is the size of the display surface measured by the LMD, w is the width of

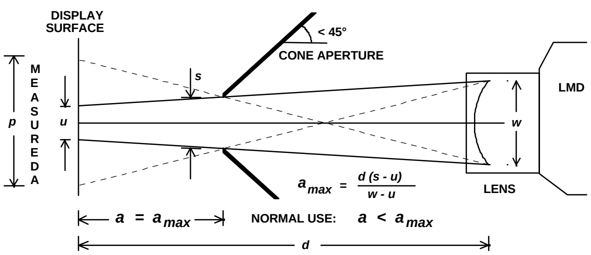

Fig. 3 Use of cone mask

the LMD lens, d is the distance of the LMD lens from the display surface, and s is the diameter of the cone aperture. In practice, a will usually be less than the limit expressed by the inequality so that the cone will not inadvertently obscure any of the measured area. This requirement on a arises from insisting that all light rays from the region viewed by the LMD can enter the LMD. As much as possible, all bright areas on the display should be outside of the region denoted by p in Fig. 2, where

$$p = \left[a\frac{(s+w)}{(d-a)} \right] + s. \qquad (4)$$

The outer diameter of the cone should be sufficient to prevent light from the edges of the screen from entering the lens of the LMD. If this is not practical, a matte black mask with a hole slightly smaller that the outer diameter of the cone can be placed in front of the cone This will eliminate lens flare from the edge of screen and at the same time not permit reflections off the matte surface from entering the interior of the cone. There will be some reflections from the matte black surface which is outside the outer diameter of the cone back onto the screen surface, that may contribute to the measurement.

Typically, the edge of the cone nearest the field of view of the LMD is not perfect, so some light can scatter from the edge into the LMD. Additionally, diffraction can contribute to the stray light especially when the cone aperture is small; in which case the edge scattering is also relatively great. We have successfully used with cone apertures as small as 5 mm.

Construction of Cone Mask

The cone mask was based on the design of an inverted-cone cavity painted with black specular paint, used in a radiometer [3]. This light trap was modified by cutting an aperture at the apex.

A cone can easily be constructed from 10 mil black vinyl plastic with a gloss surface on each side following

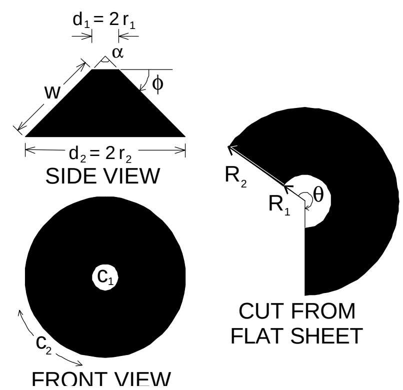

Fig. 4. Cone construction parameters

the procedure below (see Fig. 4). Given the diameter of the aperture $d_1 = 2r_1$, the outer diameter of the cone $d_2 = 2r_2$ and the apex angle a related to its complementary angle f by $f + a/2 = p/2$; we will show how to cut the proper shape from a flat sheet of plastic. We need to determine the inner flat radius R_1, the outer flat radius R_2, and the flat-angle subtended q. We can express several relationships: The length of the side can be expressed in terms of the flat radii which can also be expressed in terms of the assembled radii r_1 and r_2. Noting that the circumferences can be expressed in terms of the radii; $c_1 = 2p\, r_1 = R_1 q$ and $c_1 = 2p\, r_1 = R_1 q$, these variables can be combined in several ways. We chose the following expressions:

$$w = \frac{r_2 - r_1}{\cos\phi} = \sqrt{2}\,(r_2 - r_1) \quad [\text{ for } \alpha/2 = 45^0 \text{ cone}] \quad (5)$$

$$R_1 = \frac{wc_1}{c_2 - c_1},\ R_2 = R_1\frac{c_2}{c_1},\ \theta = \frac{c_1}{R_1},\ c_i = 2\pi r_i \qquad (6)$$

with r_1 and r_2 specified.

The straight ends of the cutout piece were butted together to make the cone. We clamped the butted edges together flat on a table (with the clamp holding the edges together at the middle of the straight edges), and placed a small amount of quick-hardening epoxy over the exposed butted edges to hold them together. After it hardened, we removed the clamp and using epoxy, glued
the butted edges on the inside of the cone to seal any small gap from light leaks. Be careful not to epoxy the cone to the table (you can use a non-stick surface like polyethylene or polytetrafluoroethylene [PTFE]). It may take a little compression of the cone in order to provide a circular hole.

Evaluation

Two different patterns were used to evaluate the masks: a black rectangle on a white background, and a white rectangle on a black background. The rectangle was measured at different sizes using a 512 x 512 pixel CCD measurement system using a 1 s exposure time, with a 105 mm lens and an infrared cutoff filter. The CCD detector array was about 1.4 m from the display surface. The cone mask was compared with various flat masks, as well as with no mask. The patterns were generated on a 10.4 inch (264 mm) active-matrix liquid crystal display.

Figure 5 illustrates the effect of veiling glare on the measurement system. In the no-mask measurement, the luminance of the rectangle greatly increases with decreasing rectangle size. In the past, many would attribute this to a problem with the display. Using the masks to remove the glare revealed that in this case, there was no change in the black luminance with size. The luminance measurements using the masks vary 0.3% or less. Figure 6 compares luminance measurements using the various masks placed against the display screen. The felt flat mask provided the lowest luminance measurement (and thus the best glare reduction), and the glossy black flat mask offered the highest luminance measurement (thus the poorest glare reduction). Note that the felt mask, being a poor conductor of heat, may be affecting the pixel luminance. White luminance measurements are also susceptible to veiling glare (see Fig. 7) .

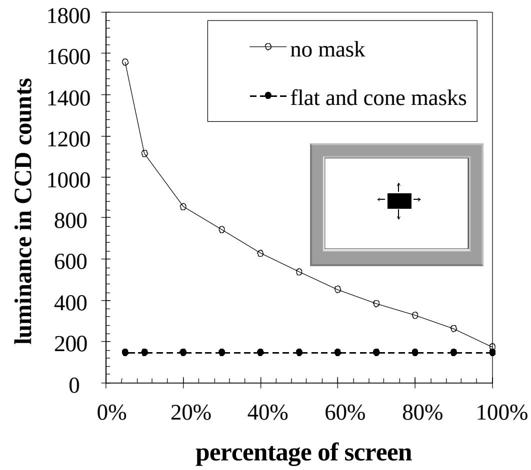

Fig. 5. Black luminance measurements

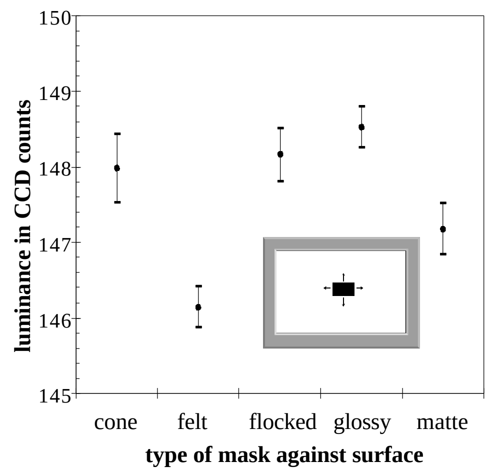

Fig. 6. Comparison of masks

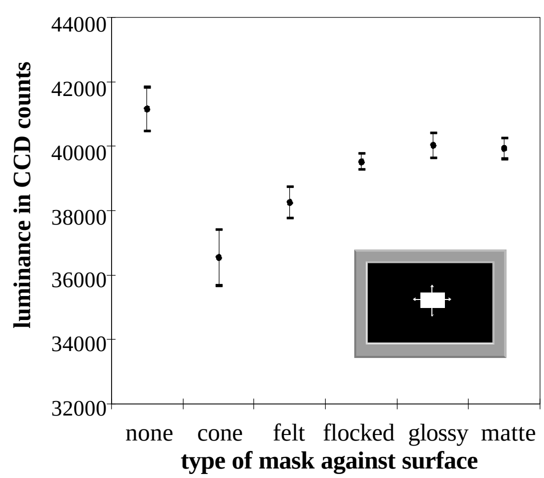

Fig. 7. White luminance measurements

We also compared the C_R measurements with no mask to those made with the cone mask. The varying rectangle patterns were again used, and the results are

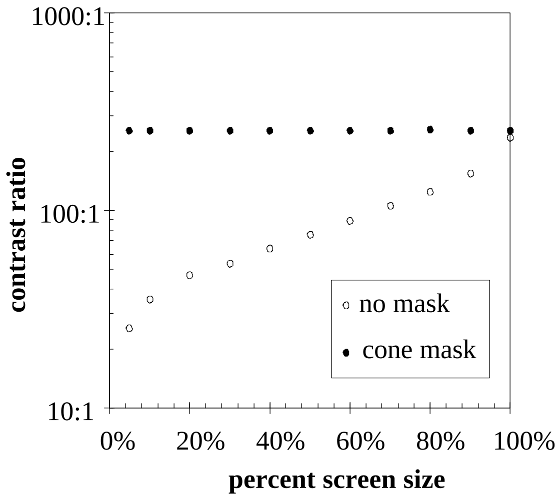

Fig. 8 Effect of cone mask on C_R (log scale)

reported in Fig. 8. The worst case indicates an error of 90%.

As mentioned earlier, it's often not feasible to place a flat mask directly on the screen. It is here that the cone offers its advantage. We measured the luminance of a 5% black rectangle as a function of the distance of the mask from the display surface. The cone was compared to the felt mask. As Fig. 9 indicates, as the flat mask is placed further from the screen, the effects of light reflecting from the mask surface become increasingly larger. The cone, if it's apex angle is 90°, can provide for a more accurate measurement.

Uncertainty

Given the number of pixels in the image measured and the average number of counts per measurement, the estimated measurement error is approximately 0.3%.

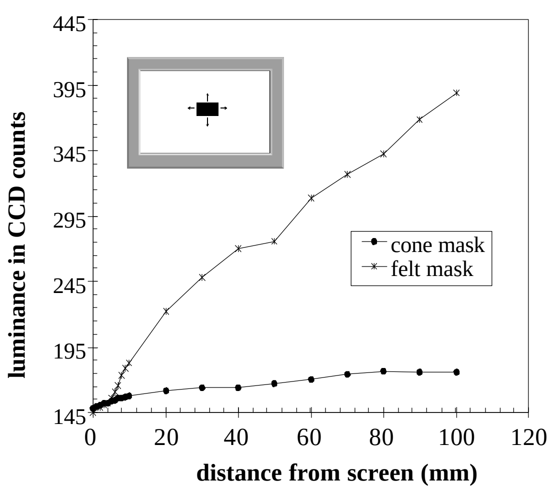

Fig. 9 Effect of mask distance on luminance measurements

The linearity and uniformity of the CCD are better than 1%. The same area of the screen was used for all measurements. For the black luminance measurements, a larger f-stop was used, and the data converted to the lower f-stop for comparison. The overall C_R measurement uncertainty is estimated to be ±2%, which is twice the estimated standard deviation.

Conclusions

Conventional methods of measuring contrast ratio and other luminance and colorimetric measurements may tend to understate the actual value due to the contribution of veiling glare. Mask apertures improve the accuracy greatly, with the cone mask offering the most flexible, non-destructive alternative.

Some "flare free" lenses use special designs, such as baffles and stops, to minimize veiling glare effects. But proceed with care. Consider Fig. 1. Assume that with a perfect lens, the black luminance is measured to be 0.2 cd/m^2 and the white luminance to be 100 cd/m^2, resulting in a C_R = 500:1 (using Eq. 1). Now assume the lens for this configuration has a flare factor of 0.1%. This produces a glare contribution of 0.1 cd/m^2, and thus the LMD measures the black luminance at 0.3 cd/m^2, resulting in a C_R of 333:1, or a 33% error.

It could be argued that such an error may not be significant. That may be so, but good intercomparison of displays and display types requires the ability to make accurate measurements. Additionally, there are high contrast applications (such as x-ray and other medical applications) for which such errors may be important. Optical systems may be very sensitive to glare, and the cone mask method provides a simple means to reduce its effect. In the future, we will examine refinements to extend the usefulness of the cone mask.

References

[1] *Methods of Characterizing Illuminance Meters and Luminance Meters*, CIE Publication No. 69 (1987). Pp. 16-17.

[2] P. Boynton and E. Kelley, "Measuring the Contrast Ratio of Displays," *Information Display*, vol. 12, no. 11, Nov. 1996. Pp. 24-27.

[3] J. Geist, L. Schmidt, and W. Case, "Comparison of the Laser Power and Total Irradiance Scales Maintained by the National Bureau of Standards, *Applied Optics*, Vol. 12, No. 11, November 1973. Pp. 2773-2776.