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Forensic Photography and Nighttime Visibility Issues

REFERENCE: Harris, J. L., Sr., and Harris, J. L., II, "**Forensic Photography and Nighttime Visibility Issues**," *Journal of Forensic Sciences*, JFSCA, Vol. 37, No. 4, July 1992, pp. 1084–1095.

ABSTRACT: Photographic demonstrative evidence can be of great value in bringing an understanding to the court regarding visibility issues involved in a nighttime scene. However, there are a number of criteria that must be satisfied to ensure the results accurately represent the visibility conditions. The use of a slide duplicating film results in good contrast fidelity and an extended luminance range. With appropriate calibration, the resulting slides can be projected with neutral-density filters used to reduce the projector output such that the luminance of the screen image is made equal to the luminance that would have existed at the scene. This is important because the thresholds of vision are heavily dependent upon adaptation level. Angular fidelity is achieved by calculating the viewing distance, which will give all scene objects their true angular size. A procedure is described that allows a numerical evaluation of the fidelity of the resulting projected images with respect to threshold observation of scene detail. This numerical evaluation procedure may also be useful in seeking the exclusion of nighttime photos that do not meet the criteria.

KEYWORDS: jurisprudence, nighttime photography, visibility, photographic fidelity

Incidents resulting in personal injury or property damage or both, and subsequent litigation, frequently raise questions as to why one or more parties failed to perceive and react to the danger at hand. In the courtroom, effort will be made to prove either that the perceptual task should have been an easy one, or, that the perceptual task would have been extremely difficult. It is certainly true that a good picture is often worth many words and, therefore, it is to be expected that there would be frequent use of pictorial demonstrative evidence such as photographs, video recordings, and computer graphics in an attempt to show the court how the situation would have appeared to the participants.

There are some very specific requirements that must be satisfied if photographs are to truly represent "how things looked at the scene." Nighttime situations impose additional difficulties and many nighttime photographs are frequently not a legitimate representation of the level of difficulty associated with visual tasks. For example, with some combination of film speed, aperture, and exposure duration, a very dark scene can be recorded on film, printed on paper and displayed in the courtroom, giving the false impression that there was substantial lighting at the scene. This article addresses the nature of the requirements that must be satisfied to achieve fidelity of viewing and offers one technique for attempting to achieve the desired goal.

The technique described in this article involves using a slide duplication film chosen because of its linearity, contrast fidelity, and luminance range. The output of the projector

Received for publication 8 July 1991; revised manuscript received 30 Nov. 1991; accepted for publication 3 Dec. 1991.

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used to display the developed slide is then calibrated by means of neutral-density filters such that the displayed image has the same luminance values as the original scene. The observers of the displayed slide will then see the scene under the same adaptation levels that existed, and the eye properties, which vary extensively with adaptation level, will be appropriate for the viewing.

Scene Fidelity

Perhaps the most important requirement for obtaining realistic photographic representations is that the scene at the time of the photography must be essentially the same as it existed at the time of the incident of interest. If the photograph is to show what an observer would have seen, it is important that the lens of the camera be placed at the observers eye position. The lighting conditions should be sufficiently similar. For nighttime photography, it is important to know that the moon is not repetitive on an annual basis. The Nautical Almanac or similar source can be used to calculate the moon position and phase at the time of the original incident and to calculate a suitable date and time that will reasonably approximate these conditions. Cloud cover can be an important factor at night even in the absence of moonlight. Low cloud cover can serve to reflect ground lighting and increase the scene illumination. Consideration must be given to any modification in the scene associated with changes, additions or deletions of artificial lighting in the area. Scene contrasts can be altered by the painting of buildings, road resurfacing, lane-line painting, etc. A check of photos taken near the incident date can sometimes provide important information in that regard. The reflectance of all surfaces can change dramatically when wet, so it is important to make a match in that regard as well.

Under some conditions, windows and windshields can have important impact on what can be seen. The cleanliness of such surfaces can be an important, and sometimes unknown, variable. Automobile headlight operating condition and alignment can also alter the scene significantly.

An exact duplication of the conditions at the scene is an unlikely event. It is important, therefore, to examine the specific manner in which the scene details may differ from those that existed at the time of the incident of interest and to assess the extent to which these differences would alter conclusions with respect to the important visibility issues. There will be times when the conditions or the uncertainty about the conditions, will preclude any reliable attempt at duplication. Frequently, however, a satisfactory duplication can be made, particularly if care is exercised to make the representation conservative from the perspective of the litigation interests being represented.

Photographic Fidelity

The principal variables that determine the visual detectability of an object are contrast, angular size, adaptation level and stimulus duration. If the objective of a photograph is to demonstrate the difficulty or ease with which objects can be detected or recognized, then the photograph must have reasonable fidelity with respect to each of these important variables. In addition, the resolution of the photograph must be such that the ability to see fine detail is limited primarily by the eye of the observer and not by the photographic process. Perfection would be a photographic representation so realistic that an observer is unable to distinguish the picture from the actual scene. Perfection is not an achievable goal with photographic imagery. It becomes a matter of considerable importance to be able to judge the extent to which the imperfections which do exist can be expected to effect the judgments of those who observe the images.

In the following paragraphs, the variables described previously and their relationship to fidelity will be discussed.

Contrast Fidelity

One of the important variables associated with quantifying the level of difficulty of a visual task is the contrast of the object of interest with respect to its background. There are a number of definitions of contrast which have been used in the literature. The definition sometimes termed "universal contrast" will be used in this paper, because, with respect to visual thresholds, it is the definition which most closely provides a quantitative measure of detectability, independent of whether the object is brighter or darker than its background [*1*]. The definition is,

$$C = (B_T - B_B)/B_B \tag{1}$$

where C is the Target Contrast, B_T is Target Luminance, and B_B is Background Luminance. A black object viewed against a lighter background, that is, silhouette viewing, has a contrast of -1. An object twice as bright as its background will have a contrast of $+1$. To a first approximation, all other factors being equal, these two objects will be equally detectable. The contrast of an object darker than its background can never be less than -1 whereas the contrast of an object brighter than its background can approach plus infinity, for example, the case of a star viewed in space against an empty background.

If the original scene is thought of as an input and the final photographic representation of the scene as an output, then the process can be described in terms of input-output relationships. Specifically, contrast fidelity will be achieved if there is a linear relationship between scene luminance and picture luminance. Suppose, for example, that there are two objects in the original scene, one of which is three times as bright as the other. If contrast fidelity is to be achieved then the images of those two objects must differ by three to one in luminance in the output picture. This is equivalent to stating that the process must be linear in terms of luminance.

The technical characteristics of the luminance linearity of photographic films are documented by the manufacturers and displayed as characteristic curves. This information is available from the film manufacturers in various publications [2]. Characteristic curves, as shown in Fig. 1, graph the relationship between film exposure and film density. Logarithmic representations are used because of the large range of the exposure values. Density is inherently logarithmic because it is defined as the $\log_{10}$ of the reciprocal of the film transmittance. Figure 2 contains the same information as that of Fig. 1, plotted as transmittance rather than density. For fidelity of scene presentation, the ideal slide film would have a transmittance linearly proportional to scene luminance. Such a linear function, when plotted logarithmically, would be a straight line with a slope of 1. Real films have both a maximum and minimum density, corresponding to minimum and maximum transmittance, and, therefore show a saturation at both density extremes. However, in the middle of the exposure range for the film, the characteristic curve will generally have a "straight line region." The slope of that straight line region is an indicator of the linearity of the exposure-transmittance relationship. A slope of 1.0 means that transmittance is linearly proportional to exposure. A slope of 2.0 means that the transmittance is proportional to the square of exposure, a strong departure from linearity. Examination of the characteristic curves for a variety of slide films [*1*] indicated the approximate straight line slopes shown in Table 1.

The first film listed is SO366, which is a slide duplication film. The table shows that the slope of this film is much closer to 1.0 than any of the other slide films shown. As can be seen from Figs. 1 and 2, at the low end of the exposure scale, the characteristic

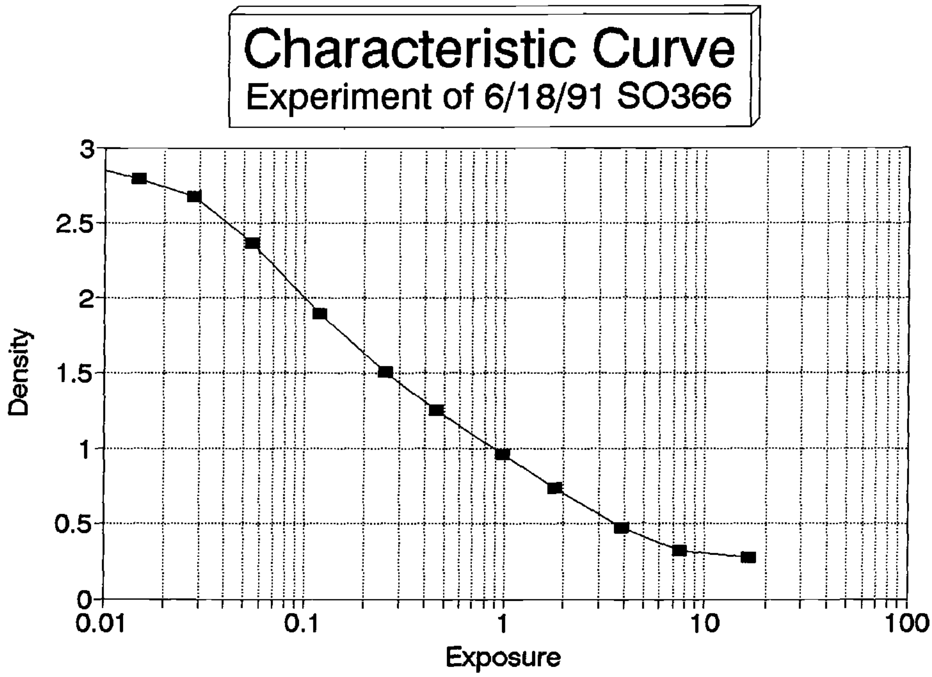

FIG. 1—*Experimental curve derived from projected gray scale slide.*

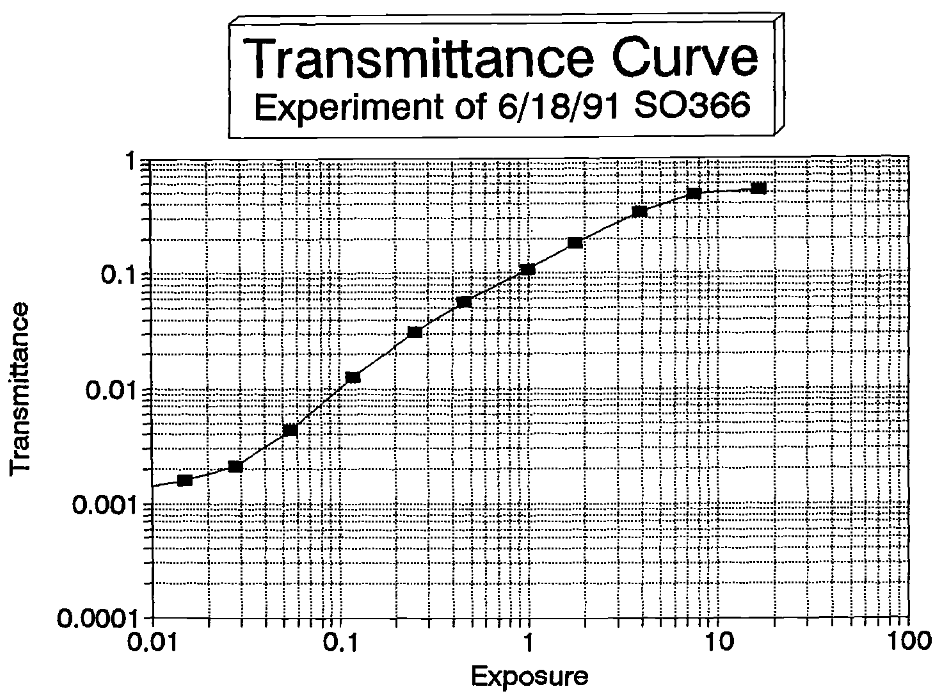

FIG. 2—*Experimental data displayed as transmittance vs. exposure.*

TABLE 1—*Approximate slope values for a variety of slide films obtained by graphical analysis of characteristic curve data.*[1]

Film Type	Straight Line Slope	Comments
SO366	0.9–1.1	Good linearity over top 1.3 logs exposure
	1.6–1.9	Contrasty over 0.7 log low exposure range
Kodachrome 25	2.0–2.3	
Kodachrome 40	2.0–2.3	
Kodachrome 64	2.0–2.4	
Ektachrome 50	1.9–2.1	
Ektachrome 64	1.9	
Ektachrome 100	1.9	
Ektachrome 160	2.2	
Ektachrome 200	2.0	Limited straight line region
Ektachrome 400	2.3	
Ektachrome P800/1600	3.0	

curve has an increased slope, but even in that region, the slope is lower than the other films listed. The low slope not only implies a more linear relationship between exposure and transmittance, but also means that the straight line portion of the curve will encompass a greater exposure range. It is for these reasons that SO366 was chosen for the nighttime photography.

The data for Figs. 1 and 2 was obtained by an experiment. A commercial gray scale was photographed over a wide range of exposures achieved by varying the f-number of the lens and the exposure time, using one stop changes, although exposure times were all chosen to be reasonably long because this is the condition which will be common in night photography using this type film. As each photograph was taken, a spot photometer was used to measure the luminance of the gray scale patches. The exposure of the film image of one of the gray scale patches can be calculated from the luminance of the patch, the f-number of the lens, and the exposure time as follows:

The flux, F, in lumens which will be received by a lens is,

$$F = B/pi * W * A_L \tag{2}$$

where B = Luminance of some scene detail in Foot Lamberts; W = Solid Angle of the scene detail in steradians; and A_L = Area of the lens aperture in square feet.

However,

$$W = a/f_2 \tag{3}$$

where, a = image plane area of scene detail in square feet; and, f = focal length of the lens in square feet.

The lens area,

$$A_L = pi * D^2/4, \tag{4}$$

where, D = Diameter of the lens aperture in feet. Substituting Eqs 8 and 9 into 7 results in,

$$F = Ba/4 * (D/f)^2 \tag{5}$$

but, f/D = f-number ($f/$) of the lens so that,

$$F = Ba/[4 * (f/)^2] \tag{6}$$

The illuminance in the image plane in the area, a, is equal to the flux divided by the area and the exposure is the product of the illumination and the exposure time, t, so that,

$$E = Bt/[4*(f/)^2] \text{ foot candles-seconds} \quad (7)$$

The film data is given with exposure units of lux-seconds. Recognizing that 1 ft candle = 10.76 lux,

$$E = 2.69Bt/(f/)^2 \quad (8)$$

The contrast fidelity of the process can be examined by taking two neighboring values of exposure, E_1 and E_2, and computing an "input" contrast,

$$C_{in} = (E_1 - E_2)/E_1 \quad (9)$$

and an "output" contrast, from the corresponding values of transmittance, T_1 and T_2,

$$C_{out} = (T_1 - T_2)/T_1 \quad (10)$$

For the purposes of this article, Contrast Factor, is defined as,

$$Q = C_{out}/C_{in} \quad (11)$$

The ideal would be a Contrast Factor of 1.0 over the entire exposure range. Figure 3 is a plot of contrast fidelity using the data from Fig. 2. The high characteristic curve slope

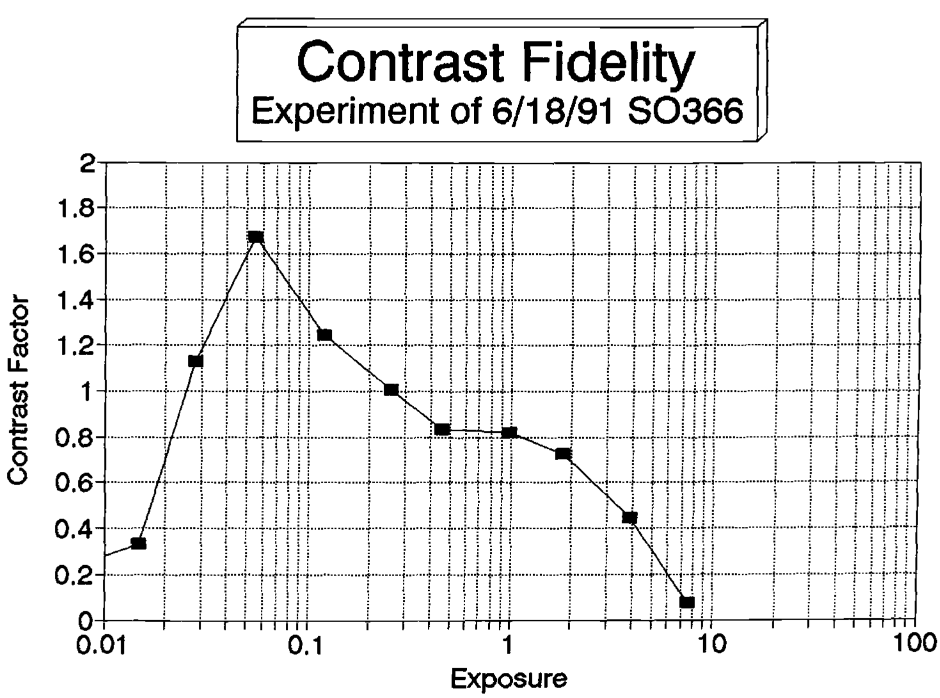

FIG. 3—*Contrast fidelity derived from the experimental data of Fig. 1.*

at the lower exposure values, which was previously discussed, is responsible for the high Contrast Factor at the low exposure values.

In using a slide with these characteristics, it becomes important to know where, on the exposure scale, the critical scene detail lies. If it is not in the region of high Contrast Factor then that deviation is not harmful. If the critical detail does fall in that region, and if the interest was in showing that the detail would have been difficult to see, then the high Contrast Factor in that region could be a problem, if, and only if, the slide tended to show that the detail was not difficult to see. If the critical detail does fall in that region, and if the interest was showing that the detail could have been seen, then criticism of the slide might be justified. In either of these cases in which the high Contrast Factor region does create a problem, there is a possible solution. It involves adding a small uniform light field to the screen, as for example from a second projector. Figure 4 shows the results of a calculation in which this procedure is simulated. The amount of added screen light is equivalent to having a second projector whose output is equal to the first, but which is projecting a uniform slide having a transmittance of 0.02. This low level of light has little effect on the Contrast Factor for the higher exposure portions of the scene.

Luminance Fidelity

When a slide is placed in a projector and displayed on a screen, the luminance of the scene is determined by the intensity of the light source, the speed of the optics, the distance from projector to screen and the reflectance of the screen. Contrast thresholds for the human visual system are highly dependent upon the luminance levels of the scene. Therefore, even if the contrasts of the original scene are reproduced with fidelity, the visual task of the observer of the screen will be different than what he would have

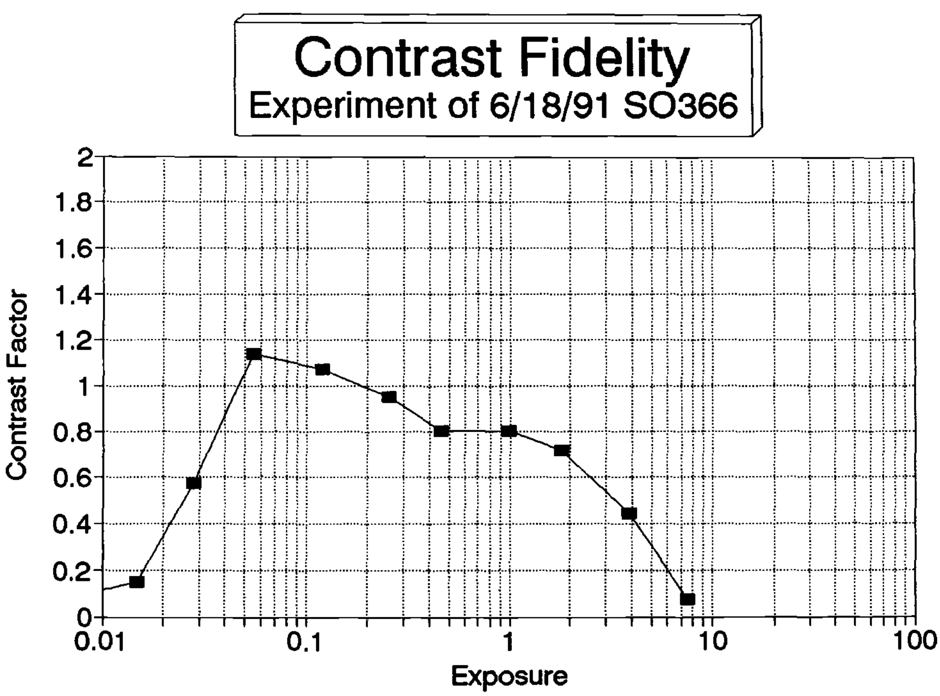

FIG. 4—*Contrast fidelity with a flooding equivalent to a transmittance of 0.002.*

experienced at the scene, if the luminance of the displayed image is not the luminance of the original scene. The changes in the visual system with adaptation level are numerous and complex. They include alteration of the relative sensitivity of the central fovea and periphery, visual acuity, and time constants of observation, to name a few. Therefore, the only valid way of presenting the scene is to make the projected scene have the same luminance as the actual scene.

Reducing the slide luminance to the correct luminance value is not accomplished by reducing the exposure in the photograph. The exposure selected for the photograph should be based upon matching the exposure latitude of the film to the luminance range of the scene such that detail of interest is displayed with fidelity. If the resulting slide projects as "too bright," then the slide projector should be adjusted to bring the luminance levels of the projected image back to those in the scene level. This can be accomplished by placing neutral density filters of the proper value over the projection lens. In a properly displayed picture, it should be possible to photometer image detail and find that the values are reasonably close to those same measurements made at the scene.

Projector Calibration

There are two methods of determining the neutral density filters that must be placed over the projection lens to properly calibrate the projector. There are advantages to using both, not only because the redundancy is a good check, but also because one of these methods may be more easily understood than the other by the judge and jury.

To understand the first method, it is important to recognize that photographic film can be used as a light meter. The science of doing so is called photographic photometry and has been practiced for many years. When a piece of film such as SO366 is exposed with a specified light energy, the product of illumination and time, and developed under standard conditions, the processed film will have a transmittance or density as predicted by the characteristic curve. Conversely, if the film is examined and it is determined to have a value of transmittance or density, the exposure that caused this reaction can be determined. In either case the exposure of the film can be related to the luminance of the scene by taking into account the f-number of the camera lens and the shutter time. The relationship is as follows:

The film data for SO366 shows that the midpoint of the exposure range is approximately,

$$\text{Log}(E) = -0.5$$

or,

$$E = 0.32 \text{ lux-seconds}$$

at which point the transmittance is approximately,

$$T = 0.04$$

Substituting this exposure value into Eq 8 and solving results in,

$$(f/)^2/t = 8.4*B_{\text{mid}} \qquad (12)$$

or,

$$B_{\text{mid}} = 0.119*(f/)^2/t \qquad (13)$$

Equations 12 and 13 establish the relationship between scene luminance and camera settings (*f*/ and *t*) at the midpoint of the exposure range. Since this midpoint corresponds to a transmittance of 0.04, the slide projector with no slide present, that is, transmittance = 1.0 will be,

$$B_{empty} = B_{mid}/0.04 = 2.98*(f/)^2/t \quad (14)$$

Equation 14 shows that the projector can be properly calibrated for displaying SO366 slides by making the screen luminance, in the absence of a slide, a value determined only the f-number and exposure time and independent of the luminance values associated with the scene.

The second method of projector calibration is to use a spot photometer to measure the luminance of prominent objects in the original scene and make the same measurements on the projected image, adjusting the projector until the two values are in agreement. This is not only a good check on the calibration performed by the first method, but is also a method that has a face validity more easily understood by the judge and jury. One problem with the second method is that the luminance of prominent objects in the scene may vary over their surface and it is sometimes difficult to insure the photometry of scene and projected scene has taken place at the same location.

A Criterion for Evaluating Photographic Fidelity

Since the projected slide cannot be a "perfect" representation of the original scene, it is important to have some means of quantifying the accuracy with which courtroom observers can draw visibility conclusions. It would be desirable to relate the difficulty of visual detection to the magnitude of the errors in contrast and in luminance of the projected image. Ricco's law [*3*] of spatial summation offers one possible basis for such an evaluation. Specifically, it states that for, unresolved visual stimuli, the product of the contrast of a visual target and the solid angle that it subtends will be a constant determined by the luminance level of the background. Since the solid angle is inversely proportional to detection distance, for a given scene luminance level, this constant can be used to determine the effect of a specified contrast error in terms of the distance at which small detail will be detectable. By considering the manner in which the Ricco's law constant varies with scene luminance levels, it is also possible to translate errors in presentation luminance into errors in the distance at which small detail will be detectable.

Using the data reported by Blackwell [*4*], for circular targets and long stimulus duration, the product of contrast and the square of angular subtense in minutes of arc was calculated for adaptation levels from 0.001 to 1000 ft lamberts. The results are plotted in Fig. 5.

From this data, the detection range errors associated with specific presentation examples can be circulated. Figure 6 shows a sample calculation assuming the contrast errors associated with Fig. 3. The upper curve is for the case of a scene having 0.1 ft lamberts luminance but displayed with a scene luminance of 100 ft lamberts. The lower curve assumes the same contrast errors but with the projector output properly reduced to the 0.1 ft lambert level.

Angular Fidelity

Common every day experience tells us that any object gets harder to see as the distance between the eye of the observer and the object is increased. Similarly, fine detail in a photograph may be easy to recognize if the jury is allowed to hold a picture a foot from his or her eye and impossible to see if the photograph is viewed across the room. The

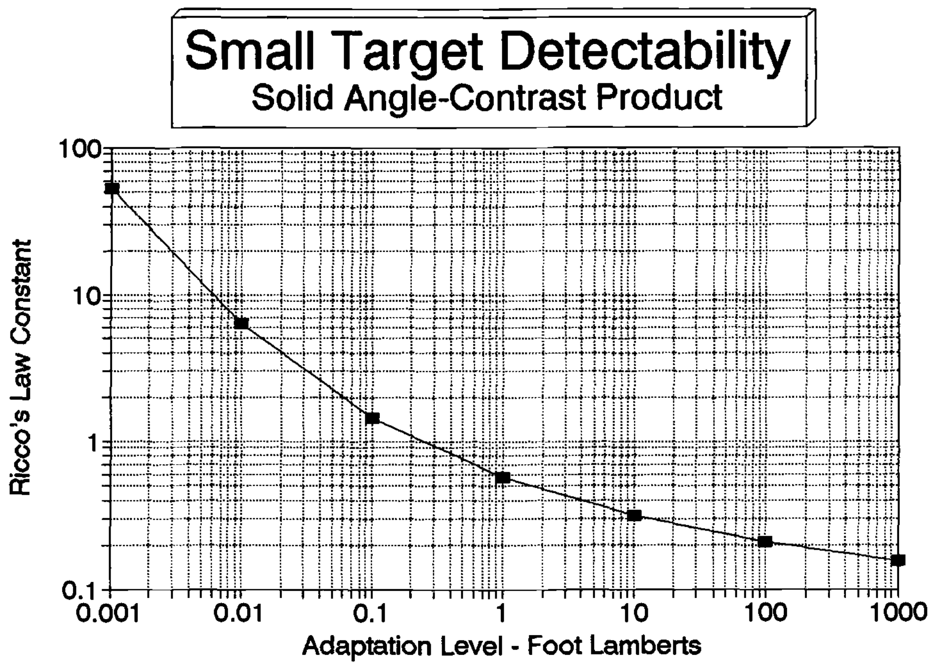

FIG. 5—*Product of contrast and solid angle from the Tiffany threshold data.*

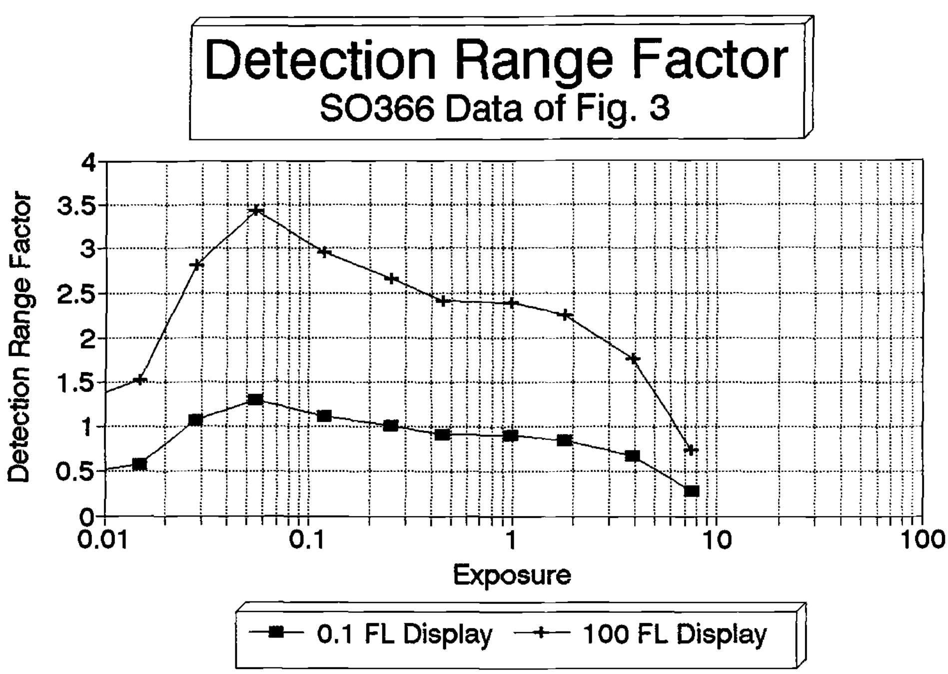

FIG. 6—*For a 0.1 foot Lamberts scene displayed correctly and incorrectly.*

fact is that, for any photographic print or slide, there is only one correct viewing distance if the level of difficulty of seeing detail is to be preserved.

A technical statement of the viewing conditions for maintaining angular fidelity is that the angular size of the image of each object in the photograph must be the same as the angular size that each object would have under the original viewing conditions. There are several practical ways of determining the correct viewing distance. One of these is to define the distance-size ratio of an object in the original scene. For example, a 5-foot-wide automobile viewed at 200 ft distance has a distance-size ratio of 200 divided by 5, which is 40. Suppose, for example, that in an enlargement of the photograph, the image of the automobile measures 1 in. To preserve angular fidelity the proper viewing distance for that photograph is 40 times 1 in. or 40 in.

The technique described in this paper involves the viewing of projected 35 mm slides. The proper distance for slide viewing can be easily established. The image size of 35 mm film format is 24 mm × 36 mm. The angular size of the smaller dimension of the field of view is determined by the ratio of the smaller dimension of the film format, that is 24 mm, and the focal length of the lens. Angular fidelity will be preserved if, and only if, the viewing ratio of the smaller dimension of the projected slide image and the viewing distance is equal to the ratio of 24 mm to the lens focal length. For example, a common focal length is 50 mm, roughly double the smaller dimension of the film format. Therefore, for slides taken with a 50 mm focal length lens, the viewing distance should be equal to twice the smaller dimension of the screen image of the slide. Such a viewing situation may not be compatible with the courtroom environment and this fact may have important practical bearing on the choice of lens focal length used to take the photographs. For example, slides taken with a 100 mm focal length lens will be properly viewed at a distance equal to 4 times the height of the screen image.

Resolution Fidelity

If the scene is to be realistically portrayed for the observer, the limiting resolution should be that associated with the visual acuity of the observer of the photograph, and not the resolution of the photograph itself. The resolving power of SO366 film is listed [2] as 63 lines per mm for a test object contrast of 1.6:1 and 125 lines per millimeter for a test object contrast of 1000:1. More detail can be obtained by examining the modulation transfer curve. The slow speed of SO366 tends to lead to the time exposures of some number of seconds duration for nighttime scenes. This means that it is generally necessary to use a relatively small *f*/number in exposing the film. A typical 50 mm focal length, *f*/1.8 lens for a 35 mm camera may have a resolution of 45 line pair per mm at the center of the picture and 40 line pair per mm at the corner of the picture [5]. As an example, assume that the camera and lens have a combined resolution of approximately 40 lines pair per mm. For a 50 mm focal length lens, one mm on the film in the central format corresponds to 0.02 radians or 48.56 min of arc of projected angle.

A resolution at the film plane of 40 lines pair per mm therefore corresponds to 0.82 line pair per min of arc. Visual acuity at daytime levels is approximately 1 min of arc. This suggests that for daytime use, a 50 mm focal length lens is somewhat marginal for photographs that are viewed under the conditions imposed by angular fidelity. For nighttime photography, however, the 50 mm lens is probably adequate for most situations because visual acuity decreases with adaptation level [6]. An interesting demonstration of the adequacy or inadequacy of resolution can be made by photographing a visual acuity chart at the appropriate distance and at the same time reading the chart to obtain a visual acuity score. This should be done at the desired adaptation level. When the processed slide is viewed at the distance defined by angular fidelity and with the projector filtered to reproduce the adaptation level at which the slide was taken, a new visual acuity score can be noted. If the photographic system has met the resolution fidelity requirements, the scores should be the same.

The Courtroom Environment

The nighttime slide technique described in this article has been used in the courtroom [7]. A hearing was conducted, in the absence of the jury, relative to the admissibility of the slide presentation. The judge ruled favorably and the slides were then used in connection with expert testimony before the jury. The experience surfaced a number of practical considerations.

It is important that the ambient room light be sufficiently low such that the contrasts in the darker regions of the projected image are not reduced by veiling luminance. It was discovered that the courtroom had small safety lights in the ceiling that could not be turned off and that the ambient illumination from these lights exceeded the allowable level. It was necessary to set up the projector and screen in a jury room in which it was possible to achieve nearly total darkness.

Invariably, the viewing distance to the screen will be somewhat different for each member of the jury. It is essential that this range of viewing distances be explored to insure that, with respect to the detail of critical interest, all viewers will draw the same conclusions as to the ease or difficulty of the visual observation involved.

The light levels of interest in this particular case were those associated with streets illuminated by street lights and automobile headlights. Under these adaptation levels, the time required for cone adaptation was minimal. This time was used to show gray and color scales and to demonstrate the use of the neutral density filters such that by the time it was desired to show the critical slides, sufficient dark adaptation had been achieved.

Conclusion

A technique for forensic nighttime photography has been described for cases dealing with visibility issues. It involves the use of a slow speed slide film, SO366, having substantial linearity such that the contrast rendition of the scene is reasonably good. The slide is then projected and neutral density filters are used to reduce the output from the projector such that the viewed image has a luminance comparable to that of the original scene. The observers, judge and jury, are thereby given an opportunity to view the scene under realistic lighting conditions and judge for themselves the level of difficulty of the visual tasks which were involved.

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