The Importance of Being Not Too Earnest

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Abstract

Impairments in imaging systems are discussed in the areas of lens vignetting, camera spectral sensitivities, reproduction gamut, tone reproduction, luminance-chrominance coding, and spatial resolution. The causes of these impairments are reviewed, and their importance discussed. Means of providing corrections are considered, and the factors determining whether such means are used or not, are reviewed; the type of scene being imaged is shown to be decisive in many cases.

Introduction

In imaging systems it is impossible to avoid errors of reproduction. Corrections for some of these errors, at least in part, are possible, but earnest attention to them may involve penalties of cost, convenience, or neglect of other errors. The importance of different types of error should therefore determine the extent to which corrections are sought.[1,2] In this context, errors in the following areas are discussed: lens vignetting, camera spectral sensitivities, reproduction gamut, tone reproduction, luminance-chrominance coding, and spatial resolution. The extent and manner in which errors in these areas are addressed often depend on the application of the imaging system being considered.

Lens Vignetting

The illuminance in an image formed by a lens is not uniform. The corners of such an image are farther away from the lens than the centre, and they are illuminated at an oblique angle by an oblique projection of the lens which reduces its effective area. This results in the illuminance falling off from the centre to the edge as a function of the fourth power of the cosine of the angle of incidence of the rays on the image plane. The effect of this on image illuminance is shown by curve A in Figure 1. It is possible to design lenses so as to reduce the extent of the fall-off somewhat, as shown by curve B in Figure 1; but it is not possible to achieve complete uniformity by changing lens design. When telephoto lenses are used, because large angles are not involved, the fall-off may be unnoticeable; but, with wide-angle lenses, the darkening of the corners of the image may be quite apparent. When images are viewed in dark or dim surrounds, as in projection, or in viewing broadcast television in low ambient light, the proximity of the dark or dim surround to the edges of the image can reduce the apparent degree of darkening by means of simultaneous contrast, so that the effect is often less noticeable than in reflection prints. These effects apply equally to electronic and to film devices.

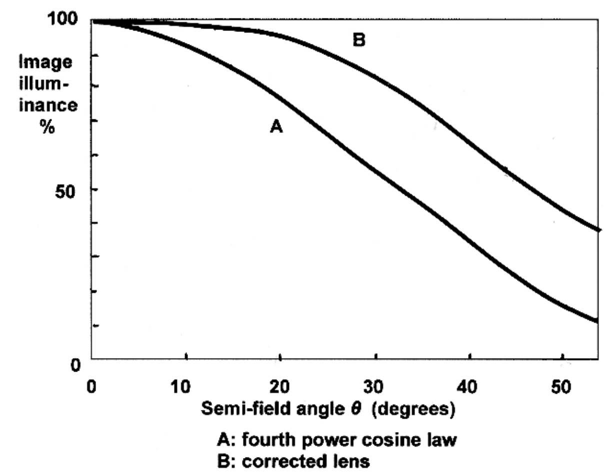


Figure 1. Image illuminance versus semi-field angle.

When negatives are used, the fall-off in the camera results in the negatives being lighter in the corners and this can compensate for the fall-off in the printer. This compensation can be complete if, as shown in Figure 2 (upper section), the negative and print material both have the same gammas (slope of the *D*-log*E* curve). But negatives usually have gammas of about 2/3 and, if used with print materials having gammas of about 3/2, the uniformity, as shown in the middle section of Figure 2, is not much better than that resulting from the fourth-power cosine function. However, the focal lengths of lenses used in printers are often greater than those of lenses used in cameras, and, as can be seen from the bottom section of Figure 2, if the angles of the rays are between about 2/3 and 3/4 of those in the camera, then very nearly uniform image illuminances can be achieved. When negatives are used on scanners using area detectors, the same principles apply; but, with scanners using linear configurations any improvement in uniformity only occurs in the across-the-page direction; with scanners using spot configurations, no improvement in uniformity occurs.

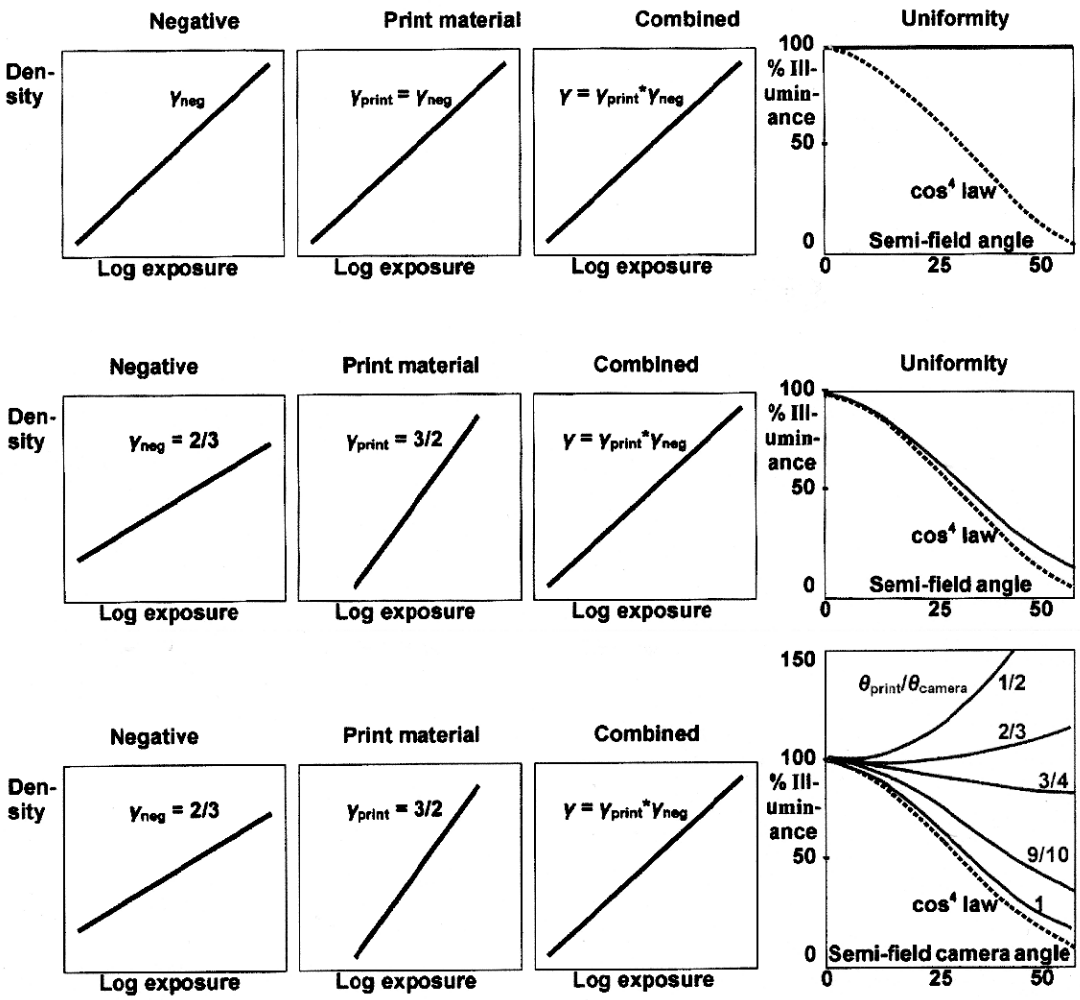


Figure 2. Top: D-logE characteristics for negative and print materials of equal gammas resulting in complete uniformity. Middle: negative with gamma 2/3 and print with gamma 3/2 resulting in uniformity only slightly better than the fourth-power cosine law. Bottom: same as middle, but with printer angles different from camera angles; uniformity is best if printer angles are between approximately 2/3 and 3 /4 of camera angle

If complete uniformity is essential, as, for instance in photogrammetry, then a graded neutral filter can be used in the image plane, or an equivalent attenuation of signals can be arranged in electronic devices; however, in both cases, there will be some reduction of signal-to-noise ratio.

Camera Spectral Sensitivities

The correct set of camera spectral sensitivities to use are the color matching functions of the primaries of the display. Other color matching functions can be used with an appropriate matrix. However, for various reasons, electronic cameras usually use spectral sensitivities that are not exactly the same as any set of color matching functions, and the spectral sensitivities of films are typically very different. In spite of this, both electronic cameras and film are well known to be able to provide very pleasing images. So how much do the discrepancies from theory matter? Perhaps the best known error caused by incorrect spectral sensitivities is the tendency for some blue flowers to be reproduced too pink on film, but some recent films are considerably better in this respect.

The extent to which the spectral sensitivities of capture devices depart from a set of color matching functions has been the subject of several studies,[3] but less attention has been directed at the robustness of the functions themselves. It is known that the color matching functions of the CIE 1931 Standard Colorimetric Observer, which are the ones that are generally used in imaging, are incorrect at the blue end of the spectrum. This arose because the color matching data was combined with the CIE 1924 $V(\lambda)$ function, the values of which were too low at short wavelengths; thus at 430 nm $\bar{y}(\lambda)$ has a value of 0.0116, whereas, although real observers exhibit a considerable spread in their results,[4] the more correct average value[5] is 0.0273, an error of 235%. It must also be remembered that the functions were based on the average results for just 10 observers in Wright's investigation and 7 in Guild's, and, as can be seen from Figure 3, there was a considerable spread amongst the observers.[6]

So to what extent do the departures from color matching functions matter? Experience has shown that they are not very important in pictorial imaging, and this is probably because of the low prevalence of extreme metamerism in naturally occurring colors,[7] and because of the spread of spectral sensitivities occurring with real observers. However, when imaging devices are used as tools in colorimetry, the errors are not negligible, and characterization[8] of capture devices then becomes important; an example of where this is done is in the DigiEye equipment.[9]

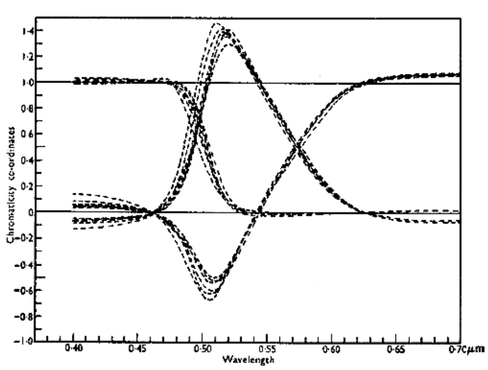
Reproduction Gamut

In additive systems of reproduction, the red, green, and blue primaries do not stimulate the three different cone types in the eye independently, and the consequent unwanted stimulations result in a limited gamut of reproducible colors. Most colors in the real world also have a limited gamut, because they depend on absorptions by dyes or pigments which are spectrally rather broad[10]. However, the additive gamut is significantly smaller than the real-world gamut, particularly for cyan colors, and the reproduction of the vivid blue-green colors of some lakes is often noticeably poor. During the development of high definition television systems, careful thought was given to the possibility of using a fourth, cyan, phosphor to address this deficiency. However, the extra cost and complexity were eventually seen as too high a price to pay for improving a rather small number of colors occurring in practice. The reproduction gamut can also be increased by using three lasers as primaries, but, again, the high cost and inconvenience of this approach has prevented it from being widely adopted.

Subtractive systems also have limited gamuts, in this case determined by the particular cyan, magenta, and yellow colorants being used. These systems usually provide slightly more cyan gamut because of their use of cyan colorants; and the use of extra colorants, such as orange, green, and violet, can sometimes be afforded for very high quality applications.

Tone Reproduction

Perfect tone reproduction may be regarded as requiring an image to exhibit the same brightnesses as the original scene. However, it is a common experience that images of sunlit scenes can be very acceptable when exhibiting the lower brightnesses produced by a very much lower range of luminances, as, for instance, when reflection prints are viewed in a living room by artificial light. This is because, in recognizing objects, the visual system pays more attention to relative brightnesses (lightnesses) than to absolute brightnesses. The reproduction of scene luminances is therefore not usually a requirement, provided that the luminances are such as to provide good cone stimulations. For projection, images should ideally have whites at luminances not lower than about 50 cd/m^2; for self-luminous displays, and projection devices intended for use in typical ambient artificial light, it is additionally a requirement that the ambient illumination should ideally be such that the luminance of whites in it should not be higher than about a fifth of that of the image whites; for overhead projectors, and for digital projectors intended for similar purposes, a light output of about 2000 lumens is desirable[11]; for reflection prints, the illumination level should ideally be not less than about 150 lux.



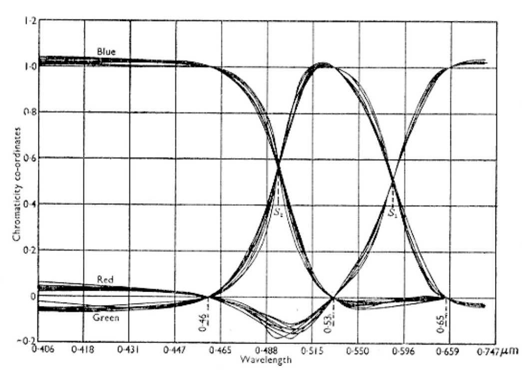


Figure 3. The chromaticity co-ordinates of the spectrum as determined by Guild's 7 observers (left), and by Wright's 10 observers (right); these data, together with the CIE 1924 V(λ) curve are the basis of the CIE 1931 Standard Colorimetric Observer.

Because surrounds to images can cause a physiological reduction in apparent contrast, increases in system gammas of about 40 to 50% are required for dark surrounds and of about 20 to 25% for dim surrounds.

Increased contrast is usually built in to systems producing reflection prints for the mass market. This tends to offset the following effects: the lower luminances in images, compared to those in real scenes, reduces apparent contrast and saturation; memory colors of familiar objects are more saturated than real colors; the small angular subtense of many images causes a reduction in contrast and saturation; and there is a tendency to discount haze more in real scenes than in images.

The dynamic range of most imaging systems is significantly less than that of many scenes and this can result in blocked-up shadows and burnt-out highlights. This is why professional cameramen make extensive use of supplementary lighting to reduce the dynamic range of scenes. Amateur photographers often use fill-in flash for the same purposes. Photographic systems also benefit from the tone-response curve having a gradually decreasing gradient as the light end of its scale is approached.

The effects of the above factors mean that optimum tone reproduction usually has to incorporate several compromises.

Luminance-Chrominance Coding

In broadcast television, by separating the information into luminance and chrominance components, considerable savings in bandwidth can be achieved. But, because of gamma correction, the luminance signal does not carry all the luminance information. The proportion of luminance carried depends on the chromaticity and is shown in Figure 4. For the chromaticity of the blue primary only 7.4% is carried, but for a large central area of chromaticity, over 90% is carried; the remainder of the luminance is carried by the chrominance signals, and their more limited bandwidth results in a loss of sharpness. Experience has shown that, for many scenes, these losses are unimportant; but, for scenes containing small highly colored areas, noticeable degradation can occur. In high-definition television, the chrominance bandwidth, instead of being reduced to a quarter, is therefore only reduced to a half of that of the luminance signal.

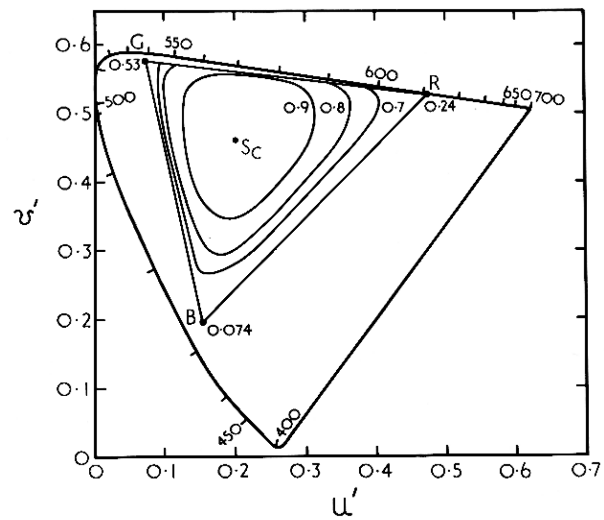


Figure 4. The ratio of the gamma-corrected luminance signal to the true luminance signal for various chromaticities.

Spatial Resolution

The resolution of electronic acquisition devices depends mainly on the number of pixels in their detectors. Although high resolution can be provided by having many pixels, this can only be achieved at high cost. It is therefore important to consider how many pixels are needed.

The resolution of the eye at a distance of 250 mms (10 inches), a typical distance for viewing a reflection print, is about 10 pixels per mm. A digital camera with 3 million detectors covered by a filter mosaic may be regarded as having only 1.5 million effective pixels, because of the need for interpolation between the filter areas. If these effective pixels are in a 1500 by 1000 array, then, remembering that visual resolution is 10 pixels per mm, the maximum picture size possible without perceptible loss of resolution is 150 by 100 mm or 6 by 4 inches (assuming that the printing system does not impair resolution by any artefacts such as dithering). This is largely borne out by experience; but larger pictures, such as 300 by 200 mm (12 by 8 inches) are sometimes acceptable. Two factors are important in this connection. First, larger pictures are usually viewed at greater distances; at a distance of 500 mm (20 inches) the resolution would not be impaired at all. Second, the apparent resolution of a picture is scene dependent; any loss of resolution tends to be very noticeable when the picture contains a lot of important detail, as, for instance, with a group of people; but, in the absence of important detail, such as with a close up of one person's face, losses of resolution may be unnoticeable. A good example of this is when a drama is broadcast on television; scenes of close-ups of the actors can appear to be very sharp; but, when the whole cast is portrayed as a group, the lack of resolution can be very obvious.

Conclusions

Impairments to image quality occur as a result of lens vignetting, the use of incorrect camera spectral sensitivities, limited gamut and dynamic range, the imperfect division into luminance and chrominance, and limited spatial resolution. The extents to which these impairments are noticeable are dependent on many factors, particularly on scene content. Means for correcting these deficiencies are sometimes available, but the earnest application of these means can be undesirable in practice; whether they are used or not depends on the severity of the problem and the cost and convenience of solving it.

Acknowledgements

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Biography

Robert Hunt worked for 36 years at the Kodak Research Laboratories in Harrow, England, taking early retirement as Assistant Director of Research in 1982. Since then he has been working as an independent color consultant. He has had two books published: The Reproduction of Colour, now in its fifth edition, and Measuring Colour, now in its third edition. He has attended all the previous Color Imaging Conferences in Scottsdale and is a regular contributor of keynote papers.