PERCEPTUAL GREY SCALE AND GAMMA CORRECTION IN THE SPATIAL PROCESSING OF IMAGES

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RESUME

SUMMARY

Abstract

Cet article presente quelques resultats de base sur l'effet du "gamma", une transformation nonlineaire des signaux en intensites lumineuses. Le gamma est present dans les tubes de television utilise egalement dans le traitement numerique des images. L'effet du gamma est notable dans le filtrage et lissage des images. Nous decrivons une methode qui preserve les avantages du gamma en television, mais reduit les effets negatifs pour le traitment numerique des images.

Abstract

In this paper, we describe some basic results of the effect of "gamma", a nonlinear transformation of signal brightness. The effect of gamma that occurs in CRTs also occurs in digital signal processing. The effect of gamma is noticable in the spatial filtering of images. We describe one method of maintaining the advantages of gamma in televisions but does not have the negative effects in the numerical processing of images.

1. INTRODUCTION

Image display systems used in image processing and computer graphics have their origins in television standards and technology. Television standards have evolved so as to take advantage of properties of human vision to present to a viewer moving images of acceptable quality, while achieving other desirable objectives with respect to bandwidth and cost.

The specific property of interest in this paper is the nonlinear response of human vision to changes in the luminance of a scene. This basic property has resulted in the standardization of CRT displays to provide a nonlinear response of the form output=(input)^g between input electrical signals and output objective luminance. The parameter g, is called the gamma of the display and takes the value 2.2 for equipment used in the USA. A compensating gamma correction is provided in the television camera [1].

As we shall discuss, these standards have distinct advantage in conventional television, but they may result in undesirable effects if digital processing is performed between the camera and the display. This is obviously the case in image processing and in computer graphics, but it will also affect the digital image manipulations which are now commonly performed in broadcasting. We shall emphasize here the effect of gamma on the spatial processing of monochrome images.

2. ROLE OF GAMMA IN TELEVISION BROADCASTING

In television broadcasting, the visual scene captured by the camera is transmitted, at a high power level, to a large number of receivers. The range of the television broadcast is determined by the ability of the transmitter-receiver system to deliver an image of acceptable quality at a low received signal strength. Thus, as in other communication systems, the signal to noise ratio and the detrimental effect of noise are the limiting factors. In television, for a given signal to noise ratio, it is possible to reduce the visibility of noise impairments by the use of gamma. This is because the sensitivity of human perception to perturbations in luminance is nonlinear. If B denotes the perceived brightness and L is the objective luminance [2]:

$$B = K_1 \log L \quad or \quad B = K_2 L^{1/3} \tag{1}$$

The logarithmic or cubic root characteristics are very close to each other over a finite range for suitable choice of constants K_1 and K_2. In general, the noise which occurs in a television broadcast system will be additive. Thus because of the nonlinearity of (1) the perceived brightness changes due to a luminance change L would be much higher at low luminance values than at high luminance values. The purpose of the CRT gamma in receiver is to compensate for that effect by providing a power law

$$L = r^g \tag{2}$$

between the received signal r and the objective luminance displayed L. Thus gamma approximately linearizes the perceptual scale between the received signal and the perceived brightness and thus decreases the visibility of noise in the dark regions of the image. The net result is to increase the threshold signal to noise ratio at which the perturbation noise will become objectionable.

The standard chosen by NTSC is g=2.2. This basic nonlinearity of television receivers (or graphics monitors) must be compensated elsewhere in the television system if the original visual scene is to be faithfully reproduced on the television screen. This is done by introducing a compensating nonlinearity in the television camera. Thus, we will have in the camera

$$s = (L)^{1/g} \tag{3}$$

where s is the electrical signal at the output of the camera and L is the luminance of the scene. The nonlinearity in the television camera is denoted as gamma compensation.

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3. REPRESENTATION OF COLOR

For a full color scene observed or recorded by a camera, luminance refers to the total light intensity at each point of the scene. Brightness is the corresponding perceived magnitude. Hue and saturation refer to the subjective attributes of color. Hue depends on the dominant wavelength of the light and ranges from blue to green to yellow, orange, red or purple. Saturation refers to the amount of color, from a tinted white to a pure, deep color. Properties of linear perception have led to the use of three objective color primaries red (R), green (G) and blue (B) to represent all or most perceived colors.

Color cameras will use color filters to record separately R, G, B. The luminance and color (chrominance) information are then generated by transformations of the R, G, B signals. For R, G, B normalized to range between 0 and 1, the luminance, traditionally labelled Y, is given by [3]:

$$Y = .299R + .507G + .114B \tag{4}$$

and the color information is given by the chroma vector in a U,V space where

$$U = .5R - .419G - .081B \quad (5)$$

$$V = -.169R - .331G + .5B \quad (6)$$

U and V are color difference signals with U = R-Y and V = B-Y.

Hue is measured by the angle of the vector U,V

$$HUE = Arc \tan V/U \quad (7)$$

Saturation is the magnitude of vector U,V

$$Saturation = (U^2+V^2)^{1/2} \quad (8)$$

4. EFFECT OF GAMMA COMPENSATION ON LUMINANCE AND CHROMINANCE INFORMATION

As mentioned earlier, the camera will provide gamma compensation. For a color camera, R, G, B are gamma compensated, so that the three electrical signals coming out of the camera are

$$R', G', B' \text{ where } R' = (R)^{1/g}, \text{ etc.} \quad (9)$$

If luminance and chrominance signals are computed after compensation, then values Y', U', V' are computed from $R'\ G'\ B'$ by equations 4, 5, and 6.

Because of gamma compensation, Y', U', V' are no longer luminance and chrominance. If the Y', U', V' signals are transmitted to a receiver and displayed by a RGB CRT (using the inverse of equations (4-6)) with a gamma g, then the displayed images are faithful reproductions of the original scene. However if the signals Y', U', V' are processed in the transmitter or receiver, then the reproduction of the image will be degraded.

Because of the inability of human vision to resolve high color detail, the chrominance signals U and V are low pass filtered to a fraction of the original bandwidth. In such a case, the reconstructed R', G', B' at the display CRT are no longer equal to R, G, B. In particular, the spatial luminance information will be degraded and there will be errors in the reproduction of chrominance [4].

5. SPATIAL PROCESSING

We now consider the spatial processing of black and white images to be displayed on a CRT monitor with a gamma of 2.2. The major unwanted effect is that average gray scale values will not be preserved in low pass filtering operations.

Consider a checkerboard with the same number of black and white pixels with values $Y' = 1$ and $Y' = 0$. The average Y' is equal to 1/2. However because of CRT gamma, the brightness of such a checkerboard is much larger than the brightness of a flat gray area with $Y' = .5$.

This is because the luminance of the display for the checkerboard is $Y=1$ and $Y=0$ with an average value $Y=.5$.

For the flat gray area with $Y' = 0.5$ we have

$$Y = [0.5]^{2.2} = 0.218 \quad (10)$$

This is illustrated in figure 1 which shows a very fine checkerboard adjacent to a flat gray area. Without the enlarged section, which demonstrates that a fine checkerboard is actually displayed, we just observe two gray areas with substantial different luminance and brightness.

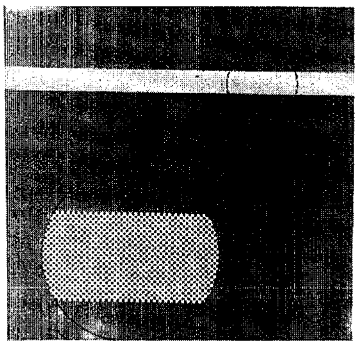
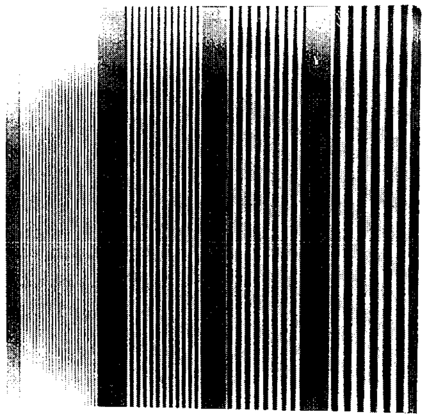


Figure 1, Display of checkerboard pattern.

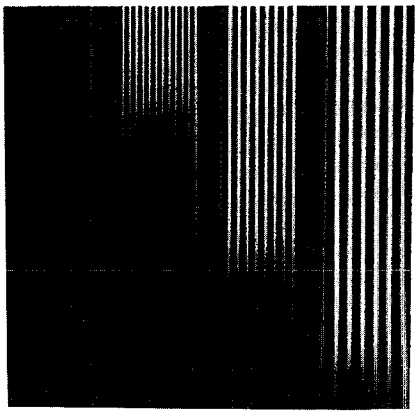
This has implications on such common digital operations on images such as filtering, interpolation and geometric transformation and resampling.

6. EFFECT ON LOW PASS FILTERING AND GEOMETRIC TRANSFORMATIONS

Whenever a filtering operation is performed on the Y' signal, we obtain at each pixel of the filtered image, a weighted sum of the Y' values in the vicinity of that pixel. This weighted averaging may modify the average brightness in a quite perceptible way. To illustrate the point, we show in figure 2a an image consisting of vertical groups of stripes, filtered horizontally by a filter which has a bandwidth decreasing vertically. Thus, more smoothing is performed progressively towards the lower portion of the image. The effect of the smoothing depends on the bandwidth of the filter and of the detail of the original image. In figure 2b we show the resulting filtered image displayed on a CRT with a gamma of 2.2. The bright portion darkens progressively in each strip, but in each strip the darkening depends on the spacing of the stripes. Thus, because of the gamma of the display, not only is fine detail removed by filtering, but the gross rendition of the image is substantially altered. By comparison, we show in figure 2c the same operation performed and displayed on a CRT with a gamma of unity. The detail of the image is removed by filtering, as expected, but the gross structure and in particular the average brightness of each strip is preserved.

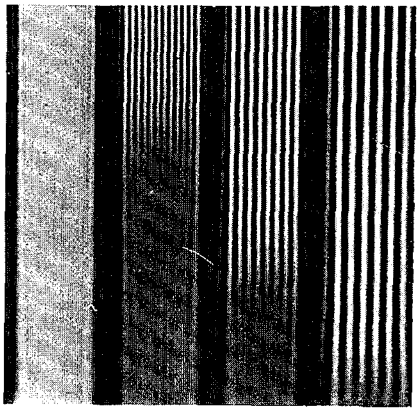


a) Original



b) Effect of Gamma

A common case of space varying filtering is whenever the geometry of the image is modified. This occurs in a number of applications of image processing, and in recent years, in broadcast television where special effects due to geometric manipulation are achieved by digital modification of the television image.



c) Gamma Corrected

Figure 2, Spatial filtering of stripes.

Figure 3 illustrates this effect. The top left image is the original building scene of San Francisco, California. The top right image is geometrically distorted. The resampling of the tall buildings result in very perceptible moire and aliasing effect. To reduce this undesirable effect, the image is digitally filtered, decreasing the bandwidth progressively toward the bottom left corner of the image. The bottom right image shows the effect of filtering when the image is displayed with a CRT which has a gamma of 2.2. The moire artifacts have been removed, but the image is very markedly darkened as a result of smoothing, as described earlier. The image at the bottom left was displayed on a CRT with a gamma of unity. The appearance of the image is substantially better than with a gamma of 2.2.

7. CONTROLLING THE EFFECTS DUE TO GAMMA

The correction of the effects due to gamma appears straightforward. That would be to use a CRT display with a gamma of unity. In fact, these CRT displays are not available and what has to be done is to perform a nonlinear compensation digitally on the image. Further, the use of gamma in television broadcast is justified by its significant reduction of visible noise. Thus the general problem is to preserve the gamma in the camera-receiver system, but to negate its effect on digital processing of images. For computer generated images, the system does not include the camera.

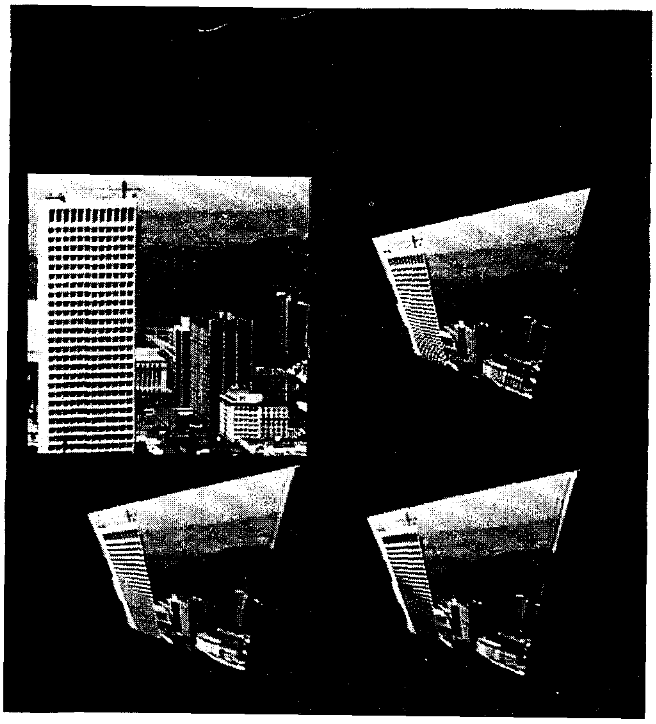


Figure 3, Geometric transformation and filtering, see text.

The solution is to provide different signal paths and digital corrections for images which are received via a communication channel and for images generated digitally.

This solution is shown in figure 4 where the two compensations are provided digitally so that both images acquired by a camera and computer generated images can be processed digitally and mixed for display.

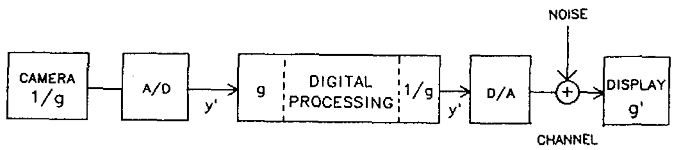


Figure 4, Gamma correction for both camera and digital images.

We have shown the channel noise after the D/A to indicate digital processing at the transmitter (in broadcast applications). Problems due to accuracy remain because the D/A converter has a fixed number of bits, typically 8. Thus the output image will only have 256 distinct gray levels in a Y' space, that is to say, still to be subjected to the gamma of the CRT. If the g and 1/g compensations are performed digitally use look up table with a small number of bits on 8 bit images, the net effect is to produce an image which has perceptible quantization steps. For computer generated images, the 1/g compensation stretches the low signal values and may result in contouring in the dark regions of the image due to quantization.

Similar problems of quantization step size occur in the digitization of the image coming from the camera. According to the speed and flexibility allowed by the equipment used, the options are to use a non-uniform D/A converter with smaller steps at low signal values, to use finer quantization in the digital images, in the g and 1/g look up tables or both.

Some additional implications pertain to the processing of color images in the Y' , U' , V' domain [5].

8. CONCLUSIONS

The properties of human vision have dictated the engineering choices and standards of television and of video equipment. Digital image processing and computer graphics make general use of the same video technology. This paper explores briefly the effect of the gamma of display CRT's on the appearance and quality of spatially processed images. We also suggest methods for mitigating the effects of gamma in digital image processing and computer graphics. A significant consideration is the accuracy in the processing and quantization of digital images.

An underlying issue in the determination of compensation and correction methods is the determination of the gamma of the display CRT and of the subjective scale from signal amplitude to perceived brightness. Simple techniques for measuring such nonlinear scales using the digital processor and display CRT themselves are given in appendix.

Appendix

Simple techniques have been devised that allow the measurement of the objective and subjective scales. These techniques make use of a CRT display and of specially designed, digitally generated test tables. The curves to be measured are $L = f_1(r)$ and $B = f_2(r)$ where r is the signal applied and L and B are the luminance and brightness respectively.

A. Scale $L=f_1(r)$

A test table is designed so that a checkerboard strips as shown in figure 1, are compared side by side with strips having a linearly varying value r. Assume that we compare side by side with a checkerboard strip with an average luminance $L_1=\alpha f_1(1)+(1-\alpha) f_1(0)=\alpha$ to a strip with lumninance $L=f_1(r)$ that is variable.

If we match the perceived brightnesses, then the average luminances also match and $\alpha=L_1=f_1(r_1)$, which provides one point on the $L=f_1(r)$ curve. Strips with r_1 ranging from 0-255 are compared side by side, in a single test table with strips with different α's obtained by changing in the checkerboard, the ratio of white pels to black pels. α is known by construction, L_1 is known by the location on the variable brightness strip.

B. Scale $B=f_2(r)$

The same basic method of comparing the brightness of strips can be used to determine differential scales for $B=f_2(r)$. A test table is designed so that the distance between adjacent strips corresponds to the commonly used 8-bit integer display. The vertical lines of the test table cannot be perceived vertically across the entire image.

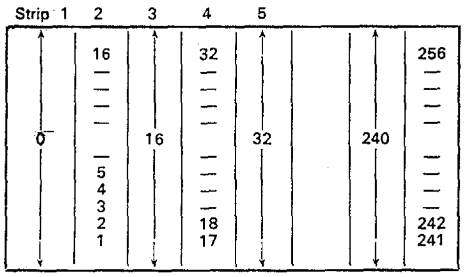


Figure 5, Test table for luminance perception.

Assume that the line between strips 2 and 3 cannot be perceived for values of strip 2 between 8 and 9. That means that 16-8=8 is the threshold of visibility of the input variable for the proposed mapping in the range of input values 8 to 16. See [6] for a discussion of computation of $B=f_2(r)$ based on these measurements.

References and Notes

[1] D. G. Fink, *Television Engineering*, London-McGraw Hill (1952), second edition.

[2] T. N. Cornsweet, *Visual Perception*, Academic Press, New York, 1970.

[3] R. W. G. Hunt, *Reproduction of Color,*, Wiley and Sons, London, 1967.

[4] A discussion of the effect of gamma on the loss of resolution on the luminance has been recently presented by R. Schafer (Heinrich Hertz Institute, Nachrichten Technik, GMBH), "High definition TV production standards - A chance for optimal color processing," SMPTE Committee for Electronic Production, Mar. 1985.

[5] R. Miller and V. R. Algazi, "The effects of gamma on digital picture processing,", Signal and Image Processing report, University of California, Davis, California, In Preparation.

[6] V. R. Algazi, "The psychophysics of vision and their relation to picture quality and coding limitations," ACTA Electronica, No. 19, Vol 3, 1976.