A psychophysical method for determining the gamma of a monitor

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ABSTRACT

Due to the nonlinear relationship between the emission of electrons and the voltage applied to the heated cathode, the output intensity of a CRT monitor also behaves in the same nonlinear manner with respect to its input. It is of great importance to correct such nonlinearity in all color calibration applications involving CRT displays. The standard gamma correction process requires the aid of a fine photometer, which is often too pricy for individual designers or small studios. We developed a quick but valid psychophysical protocol to measure the gamma of a CRT. We took advantage of human's optimal spatiotemporal sensitivity range for contrast detection. The user needs to adjust the intensity of alternating bars to minimize the flicker of a square wave. In an 8-bit per gun system, the precision of this method is comparable to that with the aids of a photometer.

1. INTRODUCTION

At present, CRT monitors are still regarded as the best display device for colour management, despite their inherent nonlinear transducer function that calls for regular linearity calibration, i.e. gamma correction. Usually high precision calibration can only be achieved with the aids of a good quality photometer. Some commercial image processing software provides gamma adjustment functions based on luminance match, yet the function is all too simple and insufficient for professional use.

We aimed to develop a quick but sound psychophysical protocol to measure the gamma of a CRT by taking advantage of human's optimal spatiotemporal sensitivity range for contrast detection.[1, 2] The precision of this method was evaluated by comparing our calibration results and that obtained with a photometer.

2. METHOD

Ideally we wish to have a linear relationship between the input voltage and the output intensity, like the straight-line in Figure 1. However, the real relationship is shown as the curve in Figure 1. The general mathematical equation for this nonlinearity is

$$I = V^{\gamma} \tag{1}$$

where I is the output intensity of a CRT monitor, V is the input voltage, and γ is the gamma to be determined in the gamma correction process.

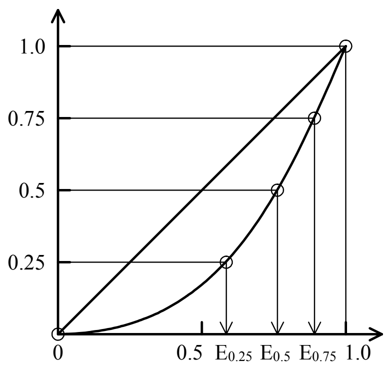


Figure 1: The relationship between the input voltage and the output intensity.

The rationale underlying a luminance-match-based gamma correction is as follows. In Figure 2, the centre square is made of 50% black and 50% white dots. Ideally, the average intensity of this patch would be the exact midpoint between that of the minimum and the maximum values. Once the intensity of the uniform background is adjusted to match that of the centre square, we obtain the $E_{0.5}$ in Figure 1. Together with the maximum and the minimum values, there are now three points available for estimating the gamma function.

Figure 2: The stimulus of the gamma correction process provided by general commercial image-processing software.

Although the above rationale is fine, in the real world the situation is more complicated due to the following factors:

(1) The image on a CRT monitor is generated by the serial scan of the electron beam on the phosphor coating. Ideally, the intensity of the electron beam should reflect the profile of an image line. However, there is a limit on the rate of current change of the system so that the electron beam cannot make an instantaneous intensity change. It always takes certain amount of time for the intensity of the electron beam to achieve a certain state. Figure 3 illustrates such behaviour. Figure 3a shows the profile of a horizontal scan line across a checkerboard pattern. Ideally the profile should be a squarewave. The actual phosphor response driven by the scan beam, however, is more like that shown in Figure 3b. There will be rounding off at the corner and a slight shift of peak and trough positions due to the time lag. As the period of the squarewave shortens, the proportion of the lag in a complete cycle will increase. When the period of the squarewave becomes shorter than twice of the sum of the rising and the decay phases of the phosphor response, there will not be enough time for the system to achieve the pre-designated values. Thus, when a pattern displayed on a CRT is made of alternating black and white pixels along the horizontal direction, the intensity will not be the same as that predicted from its digital values.

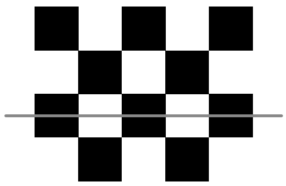
(2) The contrast sensitivity function of the human observer is highly non-uniform across spatiotemporal parameters. We are hundreds of times better at detecting the contrast of certain patterns than others. Therefore, to maximize the sensitivity of a psychophysical calibration process, one must choose the stimulus wisely. Unless the visual angle is under well control, a square patch of checkerboard is not an optimal stimulus for contrast detection.

(3) Usually only E0.5, together with E0.0 and E1.0 are used for determining the gamma function. It is too rough to fit the gamma function with only three data points.

Taking the above points into consideration, we developed a gamma correction software with the following features:

(1) The problem of sluggish intensity change is circumvented by using a pattern consisting of only uniform horizontal lines (Figure 4). The pattern used in our procedure is a horizontal squarewave. The squarewave contains two kinds of alternating strips. Type I is a uniform grey strip. Type II is composed of equal number of interleaving dark and bright lines. When the values of the dark and the bright lines are set to 0 and 1, the average intensity of a Type II strip would be 0.5. The user has to adjust the intensity of Type I strips to match that of Type II. The intensity of the Type I strip at the match will be the E0.5 in Figure 1.

(2) To place our stimuli in the most sensitive zone of human perception, the spatial frequency of the squarewave is set to 2 cpd, and the pattern is counterphasing at 15Hz. These spatiotemporal parameters are close to the optimal parameters for detecting sinusoidal gratings[1-3].



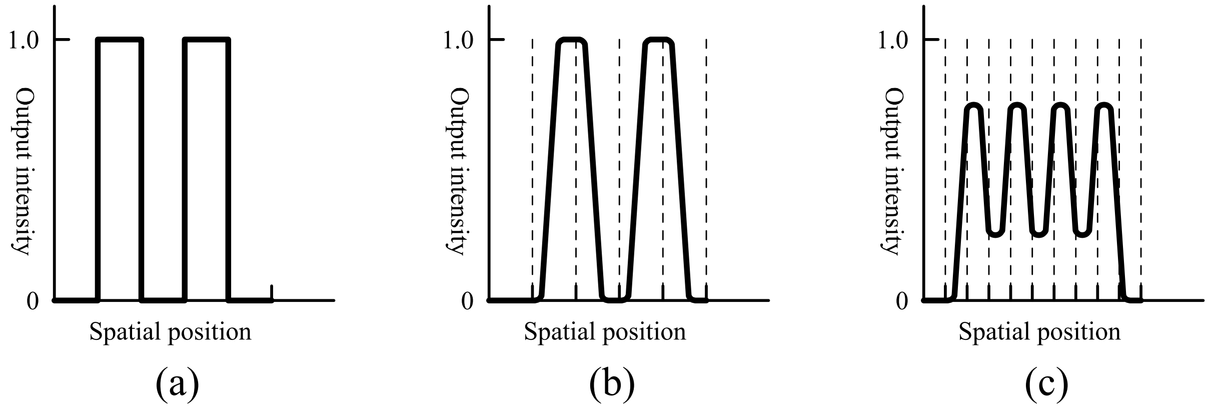


Figure 3: (a) The ideal horizontal intensity profile of a horizontal scan of the above checkerboard. (b) Due to the sluggish response of the electron beam, the actual output of the CRT shows some rounding-off and peak-shift. (c) When the spatial frequency or the alternation rate between black and white becomes too high, the output intensity will not be able to catch up with the change and is, therefore, inaccurate.

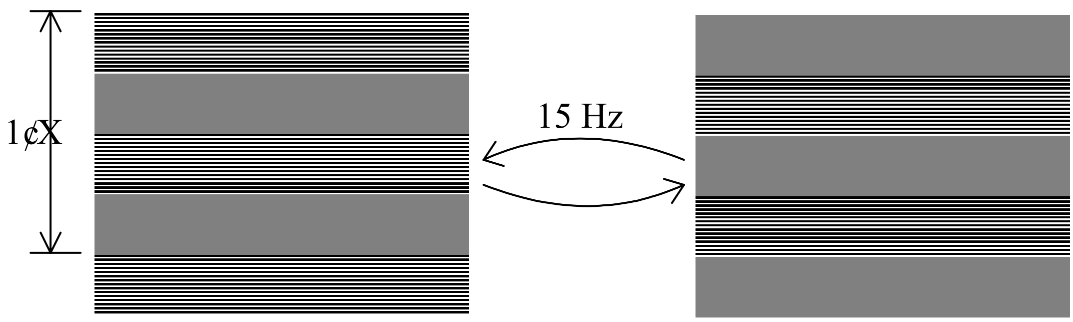


Figure 4: Stimulus of our gamma correction software. To make the contrast between Type I and Type II strips easier to detect, the pattern undergoes a 15 Hz counterphase flicker during the matching procedure.

(2) To place our stimuli in the most sensitive zone of human perception, the spatial frequency of the squarewave is set to 2 cpd, and the pattern is counterphasing at 15Hz. These spatiotemporal parameters are close to the optimal parameters for detecting sinusoidal gratings[1-3].

(3) The procedure fits the gamma function with five instead of three points, including the minimum, $E_{0.25}$, $E_{0.5}$, $E_{0.75}$, and the maximum values, as shown in Figure 1. We obtain the data points in a recursive manner. First the point of E0.5 is determined by the match mentioned previously. Then we replace the value of bright lines in Type II strip with E0.5 to obtain Type II strips of 0.25 unit intensity. The observer has to adjust the intensity of Type I strips again to find the match, which would be E0.25. The value of E0.75 can be obtained by a similar way.

Care must be taken on the viewing distance to ensure the spatial frequency of the squarewave is within the range of about 2 to 4 cpd to get the best results. In our setting a viewing distance of 220 cm was used to collect the following data.

3. RESULTS

The data presented here are the results of calibrating a CRT monitor (EIZO FlexScan T965) with the psychophysical method and with a photometer. Figure 5 (a) and (b) showed the data from two observers. The γ values are 1.81 (R^2 = .99) and 1.82 (R^2 = .99) respectively. Figure 5 (c) shows the measurement with a photometer (PhotoResearch PR650), in which the γ value is 1.83. The results from the observer agree reasonably well with that from a photometer.

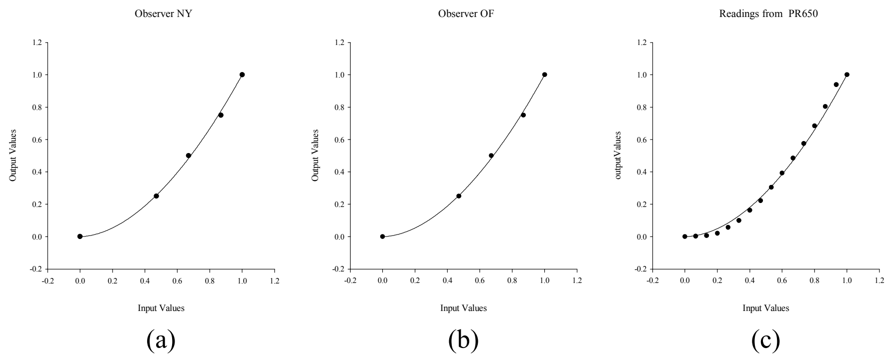


Figure 5: Data from two observers and a photometer.

4. CONCLUSIONS

Monitor calibration is of great importance for professional colour management. We have developed a software package for doing gamma correction that is easy to use and does not require a photometer. The test results show that it is as accurate as a photometer, at least in a 8-bits per gun setting. Unlike normal calibration procedures with instruments, the luminance-match-based method is robust against variations in illumination. One does not need to worry about doing the calibration under a light-proof condition. Because E0.5 is used to find out E0.25 and E0.75, one should make one's best effort to make sure the measurement of E0.5 is reliable and accurate. This calibration software should be of great value for colour management professionals.

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