An Investigation of the Effect of Image Size on the Color Appearance of Softcopy Reproductions

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Abstract

Original and reproduced art are usually viewed under quite different viewing conditions. One of the interesting differences in viewing condition is size difference. In order to develop a fundamental understanding of the effect of image size on color appearance, a digital projector and LCD display were colorimetrically characterized and used in a contrast matching experiment. At four different sizes and three levels of contrast, a total of 12 images of Gabor patterns were rendered for both displays. Twenty observers adjusted mean luminance level and contrast of images on the projector screen to match the images displayed on the LCD. The contrasts of the larger images for the projector were boosted while their mean luminance values were decreased relative to the smaller LCD images. The effect was more pronounced in the matching projected image to the smaller images on the LCD display.

Introduction

An ideal system of image reproduction includes two main subsystems, devices and software for data acquisition at the input side and devices and software for image display at the output side. The fidelity of an image reproduction system depends on the performance of the subsystems. Different techniques for spectral data acquisition have been developed and image reproduction of cultural heritage based on spectral imaging techniques has been an active research area in the last ten years. [1-3] Many art objects have a size much larger than their reproductions, whether displayed on a monitor or in print. In order to develop a fundamental understanding of the effect of image size on color appearance, a digital projector and LCD display were colorimetrically characterized and used in a contrast matching experiment. The projector and LCD display are light emitting devices and in this sense are similar soft copy media.

The physical size or viewing angle of a stimulus is one of several factors affecting color perception. Differences in size or viewing distance leads to different surrounds and as shown by Bartleson and Breneman,[4] the perceived contrasts will be different. In studies on the effect of size on the color appearance of uniform patches, an increase of lightness and chroma, but no effect on hue, for an increase in sample size was reported by Xiao *et al*. [5,6] In an exploratory experiment using a paired-comparison method, we showed that a linear increase in lightness of a small image on a LCD display resulted in a closer match to a large image projected on screen than the original colorimetric rendered image, and was perceived as a more accurate reproduction than the majority of algorithms tested.[7]

Perceived contrast is one of the perceptual attributes of an image. Michelson contrast, Weber fraction, and root-mean-square contrast are examples of metrics proposed for quantifying this perceptual attribute.[8] Sinusoid patterns at suprathreshold have been studied for their apparent contrast. It has been reported that two suprathreshold patterns generally match in apparent contrast if their physical contrast are equal, even when they have large differences in the contrast thresholds. This phenomenon is termed "contrast constancy."[9] In other words, if a test and a standard with different spatial frequencies have equal physical contrast and mean luminance then their apparent contrast will match.

An image on a projector screen, by definition, has a larger size than its reproduction on a LCD display and hence has different spatial frequencies. We have performed a visual experiment to investigate the effect of image size on percieved contrast.

Experimental

Stimuli

A sine wave pattern is a traditional stimulus used in experiments of contrast matching and visual sensitivity measurements.[10,11] The Gabor pattern is a variation of the sinusoid pattern, which is a modulation of the sine wave pattern by a radially symmetric Gaussian function. In this way the sine wave pattern fades from its maximum and minimum values to its mean value. Figure 1 shows an example of a Gabor pattern and its lightness values, in CIE L*, along the horizontal axis of symmetry. Contrast of a periodic pattern such as sinusoidal grating can be measured by the Michelson formula,[12] which is expressed in Equation 1:

$$M_c = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \quad (1)$$

where M_c is Michelson contrast and L_{min} and L_{max} are minimum and maximum luminance values, in the pattern, respectively. Three Gabor images at contrast levels of 0.97, 0.84, and 0.3 and a mean lightness of CIE L* 50 (corresponding to a luminance level of 42.65 cd/m^2) at a resolution of 3300x3300 were rendered for the LCD display. For each contrast level, using the nearest-neighbor interpolation technique, four images at resolutions of 350x350, 700x700, 1400x1400, and 2100x2100 pixels were populated. These correspond to retinal subtenses of approximately 5, 10, 20, and 29 degrees of visual angle, although strict viewing distances were not fixed in order to approximate the natural viewing conditions in a museum setting. In this way a total of 12 images were prepared. Table 1 summarizes specifications of the 12 images rendered for the LCD display. Using the LCD white point and an inverse model of the digital projector (described below), images numbered 2, 6, and 10, from Table 1, were also rendered for the projector display. Therefore, for each image on the screen, four images with the same contrast but with different sizes were rendered and displayed on the LCD display. Images on the screen had a fixed physical size of 100cm X 100cm that corresponded to a visual angle of about 28 degree and 1.1 cycles/degree. Therefore, the LCD images had approximate magnifications 1x, 2/3x, 1/3x, and 1/6x compared to the screen images. It should be noted that the white point of the LCD display was used in the renderings of all images to equalize maximum luminance level for both LCD and DLP displays.

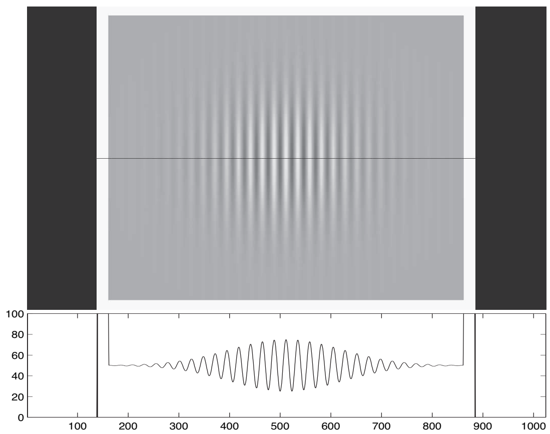

***Figure 1**. An example of a Gabor pattern and its CIE L* along the horizontal axis of symmetry (the axis of symmetry is shown by the solid black line in the image).*

Table 1- Summary of specifications of the 12 images rendered for the LCD display. (Mc=Michelson Contrast.)

No	Resolution (Pixels)	Size (mm)	Luminance Range (cd/m2)	Range of CIE L*	Cycle/ degree	Mc
1	350x350	43.6	2.1 - 165.8	10 – 90	6.0	0.97
2	700x700	87.2	2.1 - 165.8	10 – 90	3.0	0.97
3	1400x1400	174.3	2.1 - 165.8	10 – 90	1.6	0.97
4	2100x2100	261.5	2.1 - 165.8	10 – 90	1.0	0.97
5	350x350	43.6	9.6 - 107.3	25 – 75	6.0	0.84
6	700x700	87.2	9.6 - 107.3	25 – 75	3.0	0.84
7	1400x1400	174.3	9.6 - 107.3	25 – 75	1.6	0.84
8	2100x2100	261.5	9.6 - 107.3	25 – 75	1.0	0.84
9	350x350	43.6	38.3 - 70.4	47.5 - 62.5	6.0	0.29
10	700x700	87.2	38.3 - 70.4	47.5 - 62.5	3.0	0.30
11	1400x1400	174.3	38.3 - 70.4	47.5 - 62.5	1.6	0.30
12	2100x2100	261.5	38.3 - 70.4	47.5 - 62.5	1.0	0.30

Characterization of Devices

A Plus Data Projector U4-232 from Plus Vision Corp., driven by an Apple G5, was used to project rendered versions of the Gabor patterns. The U4-232 projector uses Digital Light Processing (DLP) technology and had a resolution of 1024x768. This projector is called the DLP projector through the rest of the paper. The DLP projector has four primaries, red, green, blue, and white. The white primary has been added to increase the luminous output of this display device. A device characterization model based on four primaries was proposed by Wyble, *et al*, [12,13] and was used in this research. Primary ramps of red, green, blue, and white were sampled with intervals of five digital counts in the range of 10 to 245. For the two ends, the range of 0 to 10 and 245 to 255, sampling intervals of one digital count were used. In addition to primary ramps, a set of 1000 samples was measured to verify the characterization model. For each sample, a uniform patch of the corresponding digital count was displayed on the screen and measured by a Photo Research PR650 spectroradiometer. The spectroradiometer measured radiance values in the range of 380 to 780 nm in intervals of 4 nm. All measurements took place in a dark environment. The color differences, ΔE_{00}, for the 1000 samples from the projector forward model for the 1931 standard observer were calculated and Table 2 presents corresponding mean, maximum, and 90th percentile values. The DLP projector was set to its factory standard mode during the experiment.

An IBM T221LCD display, with an area of 478 x 299 mm and resolution of 3840x2400 at a refresh rate of 12 Hz was used in this experiment. The LCD display was characterized in a dark room using the same Photo Research PR650 spectroradiometer using the Day, *et al.* method.[14] Table 2 also lists the colorimetric results for the identical dataset used by Day, *et al*.[14] As it can be seen from Table 2, both colorimetric characterizations of the DLP and LCD had good performance.

Table 2- Summary of characterization results for LCD display and DLP projector for the 1931 standard observer.

Display	Mean ΔE_{00}	Max ΔE_{00}	90 percentile ΔE_{00}
LCD Display	0.9	2.4	1.6
DLP Projector	1.0	8.4	1.6

Psychophysical Experiment

Twenty observers participated in the experiment. Using the method of adjustment, a contrast matching experiment was performed in a dark environment. Three Gabor patterns at contrast levels of 0.97, 0.84, and 0.30 were rendered and projected on a screen by the DLP projector. Each observer adjusted 12 images on the screen to match the corresponding LCD images. For example an image with a contrast value of 0.97 on the screen was compared and adjusted to four images of the same contrast but with sizes of 43.6, 87.2, 174.3, and 261.5 mm on the LCD display. Observers were asked to match the appearance of images on the LCD and screen by adjusting the mean luminance level and contrast of the image displayed on the screen. Pairs were selected in a random order from the available 12 pairs. Furthermore, the test image on the screen had an initial contrast and mean luminance level selected from a uniform random distribution. There was an interval of 10 seconds between each adjustment. Observers were asked to ignore artifacts caused by aliasing and quantization. All images on the LCD display and screen had a white margin. The background and surround of the images on the screen and LCD display were set to a black color. The LCD display and DLP screen were positioned at a 180° angle from one another. The observer was standing 50 cm from the LCD display and about 200 cm from the screen. Due to the specific experimental arrangement, an observer could not see both the LCD and screen at the same time and the adjustments were based on short-term memory matching. Observer responses were saved as data files and used to redisplay and measure the minimum, maximum, and mean luminance values with the PR650 spectroradiometer.

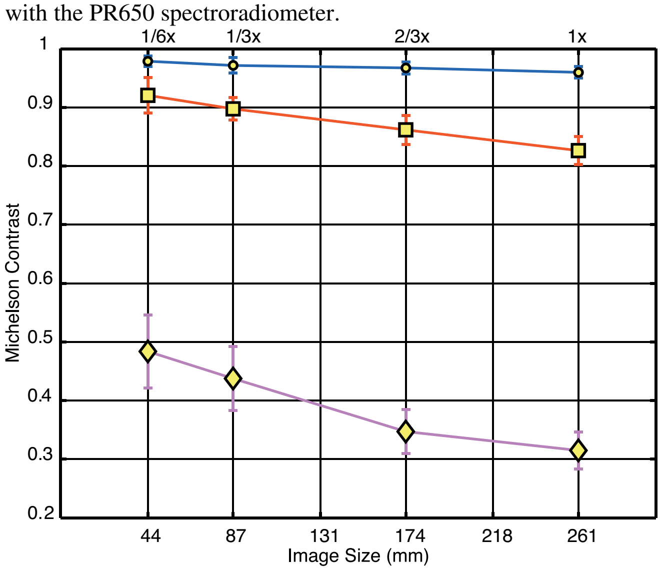

***Figure 2**. Mean of adjusted contrast of images projected on screen versus the size of images displayed on the LCD for three contrast levels. Solid blue line with circle: contrast = 0.97; solid red line with square: contrast = 0.84; solid magenta line with diamond: contrast = 0.3. Error bars present 95% confidence limits for mean values.*

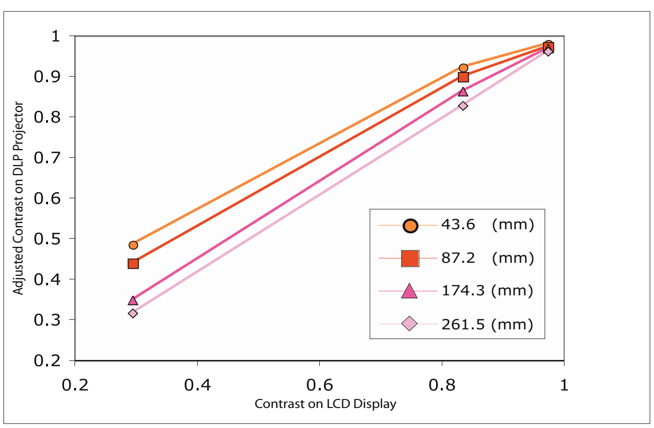

***Figure 3**. Mean of adjusted contrast of images displayed on the DLP projector versus contrast of the same images on the LCD display for different image sizes. Line with circle: size = 43.6 mm; line with square: size = 87.2 mm; line with triangle: size = 174.3 mm; line with diamond: size = 261.5 mm.*

Results and Discussion

The minimum and maximum luminance values measured from observer responses were used to calculate contrast according to Equation (1) for adjusted images (projected on screen). The mean of adjusted contrasts was calculated for each image size. A 95% confidence interval was computed for each mean value.[15] Figure 2 shows the mean of the adjusted contrast and corresponding confidence limits for the projected images versus size of the images displayed on the LCD for three contrast levels. As seen in Figure 2, for contrast values of 0.84 and 0.3, there was an increase of contrast for adjusted images when image size was decreased on the LCD display. The smaller the image on the LCD, the higher the adjusted contrast for images on the screen. However, a significant increase for adjusted contrast was not observed for the high contrast images. Figure 3 presents the same data in another way, the adjusted contrast of images on the screen versus contrast of the corresponding images on the LCD display. For contrast values of less than 0.85, the contrast of images with different sizes displayed by LCD are mapped to different contrast values for images on the screen but are mapped to the same value as the contrast level is increased.

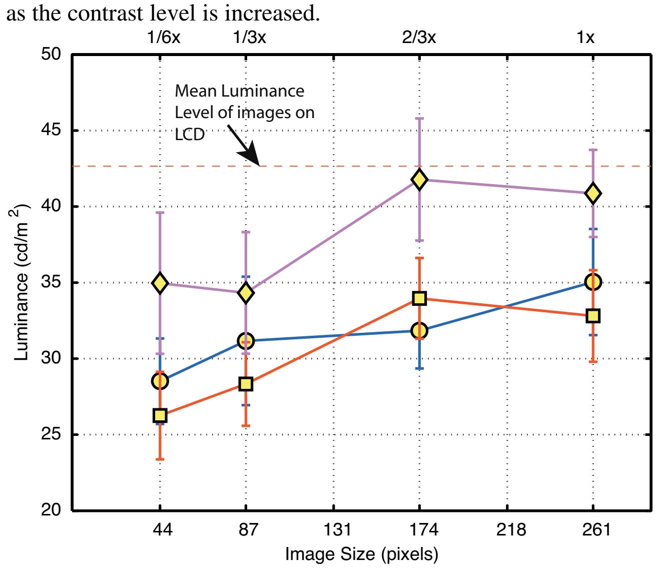

***Figure 4**. Mean luminance levels of adjusted images projected on screen versus size of images displayed on the LCD for three contrast levels. Solid blue line with circle is for contrast level of 0.97; solid red lines with square and solid magenta line with diamond are for contrasts of 0.84 and 0.3, respectively. The mean luminance level of 42.65 cd/m^2, corresponding to the CIE L* 50, is also shown by the dashed line. Error bars represent the 95% confidence intervals.*

Figure 4 shows the mean luminance levels of the adjusted images on the screen versus the size of the corresponding images displayed on the LCD for the three contrast levels. The mean luminance level of the images displayed on the LCD, 42.65 cd/m^2 corresponding to the CIE L* 50, is also shown as a dashed line. For each mean value, a 95% confidence interval was computed and shown as error-bars in Figure 4. For images of contrast values of 0.97 and 0.84, the mean luminance values of the projected images were reduced compared to displayed images on the LCD. This decrease in mean luminance value was more pronounced in the case of smaller images on the LCD. For low contrast images, contrast value of 0.30, the same trend was seen for adjusted images compared to LCD images with size of 1/6x and 1/3x, but the mean luminance values of the adjusted images were not statistically different from corresponding values of images on the LCD with a size of 2/3x and 1x (confidence intervals overlap with the dashed line). In our previous experiment,[7] we showed that the lightness of the image on the LCD was increased compared to the image on screen which is in agreement with the decrease in luminance level in the adjusted image on screen in this experiment. Xiao and coworkers,[5,6] also have reported an increase of lightness for an increase in sample size for uniform patches.

For this experiment an increase of physical contrast on projector screen images was needed to achieve an equally perceived contrast on both displays and contrast constancy did not occur. However, the curves in Figure 2 flattened for higher contrast values and for the highest contrast values, the images were almost contrast constant.

Conclusions

Both displays had good colorimetric characterization accuracy. It was shown that both mean luminance level and contrast were affected by image size and hence image size should be considered in softcopy reproduction. The method of adjustment utilized in this experiment successfully showed a trend of the increase of contrast in adjusted images versus the decrease of image size on the LCD display. For high contrast images this increase in contrast was insignificant. Compared to the mean luminance level of the LCD images, a reduction of the mean luminance level of the adjusted images was observed. This decrease was more pronounced for smaller images. Low contrast images with a size of 2/3x and 1x and corresponding adjusted images on screen had the same mean luminance values.

The decrease in luminance level in the adjusted images on the projector screen is in agreement with the result of our previous experiment in which the lightness of the image on the LCD had increased in order to make a match.[7]

Complete contrast constancy was not observed in this experiment. An increase of physical contrast on screen images was needed to achieve an equal perceived contrast on both displays. However, for the highest contrast images the required increase in contrast was lower. The higher contrast the greater the degree of contrast constancy.

Future research will explore chromatic contrast matching at other contrast and mean luminance values with the goal of developing a fundamental understanding of the effect of image size on color appearance. This research will be applied to the reproduction of cultural heritage in order to improve the ability of appearance reproduction.

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Acknowledgements

This research was supported by the Andrew W. Mellon Foundation, the National Gallery of Art, Washington, DC, the Museum of Modern Art, New York, and the Institute of Museum Library Services, as part of the Art Spectral Imaging Project

Author Biography

Mahdi Nezamabadi received his B.S. and M.S. degrees in Textile Engineering from Amirkabir University of Technology in 1992 and 2001 respectively. He had worked as industrial engineering manager at Harir Dyeing & Printing Company from 1994 to 1997. From 1997 to 2002 he has been working as a lab instructor and researcher in the Color Science Department of Amirkabir University of Technology. Since 2002, he is a Ph. D. student in Imaging Science at the Munsell Color Science Laboratory of Rochester Institute of Technology.