INVESTIGATION OF COLOR APPEARANCE USING THE PSYCHOPHYSICAL METHOD OF ADJUSTMENT AND COMPLEX PICTORIAL IMAGES

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A technique was developed and tested for generating CRT image reproductions that matched the color-appearance of print originals. Five observers matched two scenes using a memory matching technique. Observers were able to produce accurate matches when originals and reproductions were viewed at the same white point. Observers matched the reproduction at 6500K to originals viewed at 9300K and at 3000K. These matches were compared to the predictions of various color appearance models using a paired-comparison technique in a second psychophysical experiment. The observer-matched images were found to be equal or superior to all predictions of the models tested.

INTRODUCTION

The need for accurate color-appearance reproduction across different media is becoming increasingly important. Colorimetric matches are acceptable when all viewing conditions are equal between media, a situation that is only feasible in a laboratory. Simple chromatic-adaptation models such as von Kries and CIELAB are useful when white-point chromaticity differs, but do not include effects of luminance level changes, induction due to background, surround effects, incomplete adaptation, or cognitive mechanisms of adaptation. More comprehensive models have been proposed to predict color-appearance matches across different viewing conditions. These include RLAB,[1] LLAB,[2] and models by Hunt[3] and Nayatani *et al.*[4]

In order to test color appearance models for imaging applications using magnitude estimation or a paired-comparison technique, reproductions must be calculated based on the original image data as well as information about the viewing conditions of the original and reproduction. Because the field of color-appearance modeling is still maturing, models are continually being modified and improved. Therefore results of a psychophysical experiment to test color appearance models might quickly be outdated. The goal of this research was to develop a technique to generate color-appearance image data independent of any color appearance model. Observers viewed original printed images in one viewing condition and adjusted CRT reproductions under a second viewing condition to match the originals. The colorimetric data from these matching images were used to test current models and could be used to test future modifications or new models without need for further observations.

EXPERIMENTAL

Observers adjusted CRT reproductions using Adobe Photoshop™ 3.0.1 to match original images. CRT images were surrounded by a gray field consisting of 50% white pixels and 50% black pixels. In the first experiment, the original image that observers matched was also viewed on the CRT. In this experiment, the original and reproduction were viewed successively to simulate the viewing situation of subsequent experiments in which white points differed. This also caused the images to occupy the same position on the CRT to avoid spatial nonuniformities. For the remaining three experiments, original images were viewed in a light booth, with chromaticities approximating CIE Illuminants D65 and A, and 9300K. All experiments were conducted in a completely darkened room so that only the print or CRT image occupied observers' fields of view. A divider prevented observers from viewing the print and CRT images at the same time. The images subtended an angle of approximately 17° in the observers' field of view (as measured across the diagonal of the 6" x 8" images).

Two digital color scenes containing pictorial information were used in the adjustment experiment: a fruit basket and two golfers. Original images were printed using a Fujix Pictrography 3000 continuous-tone digital printer. Images included a thin white border that was adjusted and modeled as part of the image. The prints were mounted on spectrally non-selective gray cardboard with a luminance factor equal to 50% of the white border. The printed images were digitized before mounting using a Howtek Scanmaster D4000 drum scanner to provide RGB data for preparing the CRT reproductions. The scanner was colorimetrically characterized such that scanner RGB tristimulus values could be accurately converted to CIE XYZ tristimulus values for the actual spectral power distributions present in the light booth.[5]

Printed original images were illuminated and viewed using various fluorescent lamps in a GTI Soft-View light booth. The lamps included a Macbeth 6500K, a Graphlite 5000K, and a General Electric Soft White (approximately 3000K). The white-point chromaticities for the print images were measured off the image border and differed from those of the sources (*i.e.*, the paper was not nonselective). Reproductions were displayed on an Apple Multiple Scan 20 CRT with white-point chromaticities closely approximating those of CIE Standard Illuminant D65. This CRT was controlled by a Power Macintosh 8100/110 and colorimetrically characterized using established techniques.[6] For each scene, observers began with two different initial reproductions that they adjusted to match the original image. These differed from the original according to typical device-dependent image transformations (not simple digital manipulations). Similar viewing conditions were used for the paired-comparison experiment.

Five observers performed this adjustment experiment for each of the viewing conditions. All were experienced in using the color adjustment tools and tested for normal color vision. While successive viewing was used, observers were required to adapt to each display for 60 sec. prior to making any judgements. They were advised to shift their focus around the scene such that they would not locally adapt to colors in the scene.

A paired-comparison experiment was performed by 32 naive observers to determine whether the adjusted images matched the original images at least as well as those predicted by various color appearance models. These models included RLAB, the Hunt model, CIELAB, and von Kries chromatic adaptation. Linear XYZ-to-XYZ matrix transformations were derived to predict the adjusted images from the originals. Images derived using these matrices were also compared to the average adjusted images and the model predictions. In total, seven reproductions were compared, resulting in 21 pairs. To further test the ability of the models and matrices to predict matches, a third scene (an outdoor image of a barn) was introduced that was not used in the adjustment experiment. The order in which the three scenes were shown was varied for the 32 observers. Observers used the memory viewing technique for comparing the reproductions to the original images. Observers adapted to a gray card in the light booth for 60 sec. before viewing the original printed image. They studied this original print until they were comfortable that they could remember it and then the light booth was covered. Observers viewed a gray field on the CRT at a luminance level approximately equal to the background of the print for 60 sec. before viewing the pairs of reproductions. Then they chose which of the two reproductions looked most like their memory of the original image. Observers were required to look back at the original print in the light booth (including the 60 sec. adaptation cycle) after having made approximately half of the 21 comparisons.

RESULTS AND DISCUSSION

In experiment 1, both original images and reproductions were viewed on the CRT with a D65 white point. The average CIELAB color difference, calculated for various object regions, between original and adjusted reproduction was about 3.1. This is on the order of average perceptibility tolerances for complex pictorial images. In experiment 2, observers made accurate tristimulus matches between the CRT and the printed originals viewed in the light booth under D65. The average color difference between the original and the adjusted reproduction were about 3.6 in this case. The color differences in the cross-media experiment were slightly higher than experiment 1. This increase in color difference was surprisingly small considering the added constraint of remembering images over the 60-sec. adaptation period that was not present in experiment 1. Observer metamerism could also account for this increase in uncertainty. The results of the first two experiments define the accuracy of the data for changes in viewing conditions obtained in the final two adjustment experiments.

Figure 1 shows the calculated color difference between the average adjusted reproduction and reproductions predicted by various models for 3000K-print to D65-CRT conditions. (Similar results were obtained for the 9300K to D65 experiment.) As expected, the models derived from the adjusted images, namely the three matrix images, had a smaller color difference from the adjusted images than any of the color appearance models. The image derived from the Golfer matrix (GoMatrix) had higher color differences when applied to the Fruit scene than the Golfer scene, and the reverse was true for the Fruit matrix (FrMatrix). The Average matrix (AveMatrix) was a good compromise between these matrices. RLAB, CIELAB, and LLAB produced color differences on the order of 6 units, von Kries produced differences from 6 to 8 units, and spectral sharpening, the Hunt model, and Nayatani *et al.* model produced differences greater than 10 units.

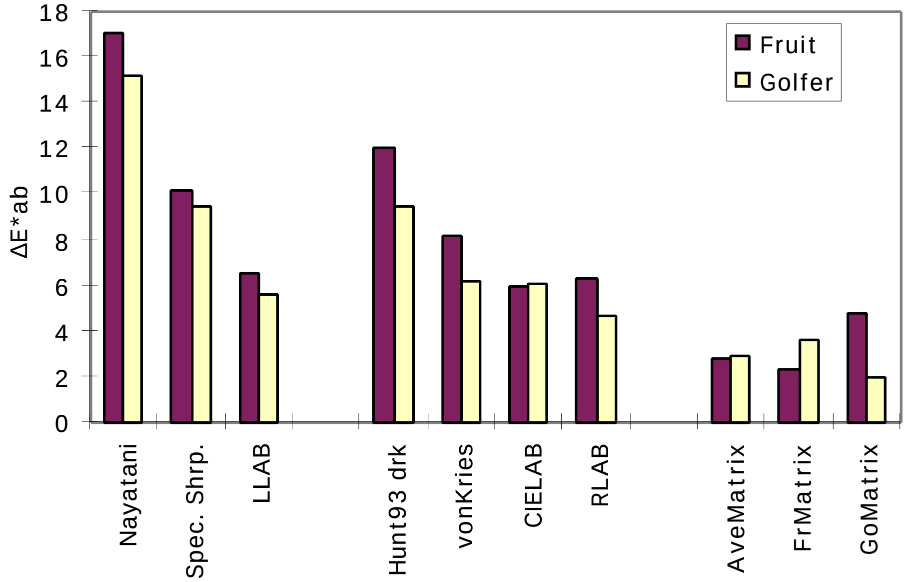

Figure 1. ΔE^*_{ab} between average adjusted images and color appearance model predictions.

Results of the paired-comparison experiment using the same viewing conditions are given in Figure 2. The scale values and 95% confidence intervals were derived using Thurstone's Law of Comparative Judgements. The average adjusted reproduction for the Fruit scene produced a match that was as close to the original as reproductions calculated from the matrices, RLAB, and CIELAB. Observers found the match between the Golfer adjusted image and the original to be superior to images produced with any other transformation. The matrix found using both images gave good results on all scenes including the independent Barn image. Comparing to Figure 1, CIELAB and RLAB produced approximately equal color differences from the adjusted image for the Fruit image

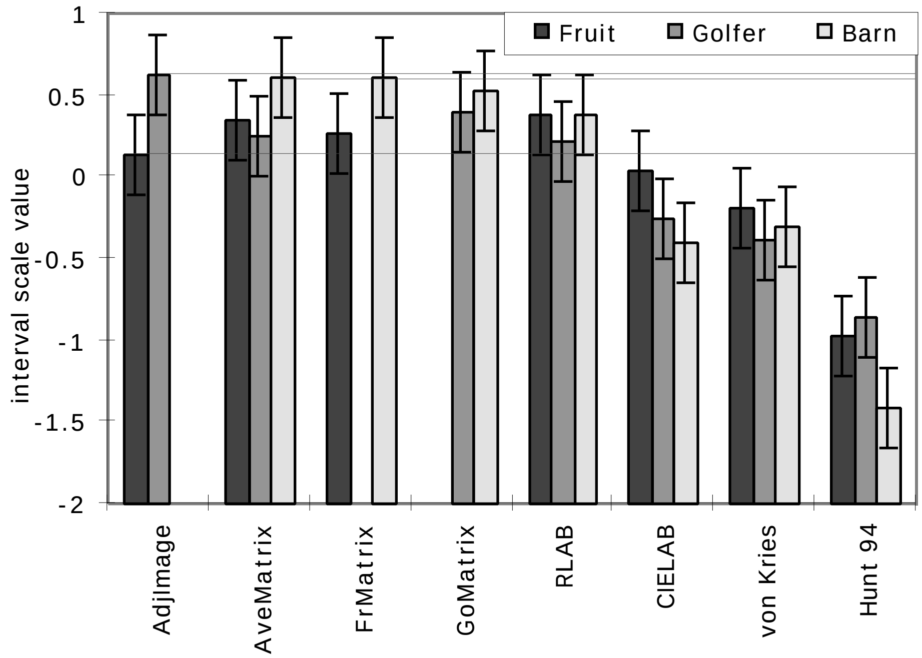

Figure 2. Results of paired-comparison experiment using average adjusted image, images determined from matrices, and color appearance models. Error bars represent 95% confidence intervals.

yet in the paired-comparison experiment, RLAB performed significantly better. Similarly RLAB produced equivalent results to the matrices in the paired-comparison experiment but was significantly worse in the ΔE^*_{ab} calculations. However, RLAB produced a smaller ΔC^*_{ab} than CIELAB and approximately equal to the matrices, which corresponds well to the above observation. Perceptual differences between images seem to depend on which attribute is being varied (lightness, chroma, hue, contrast, *etc.*) This indicates the need for development of a metric other than ΔE^*_{ab} to more accurately describe the perceptual difference between two images.

CONCLUSIONS

It has been shown that, using an adjustment technique, observers can produce consistent matches over the required 60-sec. adaptation period and across a change in media. This adjustment technique resulted in images that matched at least as well to printed originals as reproductions created using color appearance models. Some restrictions of the technique are that observers must be proficient in Adobe Photoshop™ and must spend about a half an hour per image to make an accurate reproduction. In order to derive a new model of color-appearance, this experiment must be repeated for a wide range of viewing conditions and image content.

According to the results of the paired-comparison experiment, the RLAB color appearance model produced good cross-media matches for all three images. The CIE color differences between the adjusted images and the RLAB reproductions were approximately equal to those produced with LLAB and CIELAB. In order to accurately compare models to adjusted images derived using the technique described here, metrics need to be developed that better correlate to perceived color-appearance differences. The results of the adjustment technique using the two scenes in this experiment agreed reasonably well.

For these white-point changes, chromatic adaptation was modeled well by linear 3x3 matrices. Such relationships, while valid for chromatic adaptation at constant luminance, would not be expected to hold for changes in luminance or surround. Further data are being collected to test this hypothesis. Additional details on the work presented in this paper can be found in references 7 and 8.

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