Title:
The Effect of Colored Lighting on Color-Depth Perception – Comparing Two Techniques in HDR Image Generation

Authors:
Ruth Genevieve Ong, ruth.genevieve@gmail.com, National Taipei University of Technology
Nan-Ching Tai, nctai@ntut.edu.tw, National Taipei University of Technology

Keywords:
Color-Depth Perception, Chromostereopsis, Colored Lighting, High-Dynamic Range Imaging, Radiance

DOI: 10.14733/cadconfP.2015.346-348

Introduction:
Chromostereopsis (color stereopsis) is a phenomenon wherein colored objects on the same plane appear to be on different planes [2],[4] and prior research on this topic have been mainly been about the physiological and optical causes. But in a three-dimensional world, there are many more factors to consider than just physiological or optical causes for chromostereopsis, such as perceptual causes [5]. Studies on the perceptual basis for chromostereopsis have emerged over the years, which includes border contrast between a target and its surround [1]. However, many of the studies did not incorporate the effect of lighting; the ones that did only tested the illumination level, not its spectral composition.

Lighting, especially colored lighting, has been known to affect color appearances of objects, but none have explored how lighting could affect chromostereopsis. In a previous study that explored just that, the visual stimuli used for the psychophysical experiments were high-dynamic range (HDR) images produced by combining captured low-dynamic range images of a scaled model, thereby creating a radiance map. However, the materials available commercially can limit the range of colored lighting conditions that could be tested. Furthermore, the output images show some degree of camera shake despite attempts to minimize camera movement during image capture, resulting in minor (possibly negligible) misalignment and image blur in the final HDR image.

In this study, we attempted to replicate the previous experiment by using another technique to generate the HDR images (namely, physically-based rendering), to test whether better visual stimuli can be produced. The RADIANCE lighting simulation system is a physically-based rendering application capable of complex and accurate lighting calculations [6], and can produce high-dynamic range images required for the experiment. In addition, RADIANCE has the flexibility to accurately process RGB values (measured from the materials used in the scaled model experiment) for lighting calculations, and was therefore suitable for the current study. We explored whether the observed chromostereopsis using the two techniques in HDR image generation or acquisition will be similar or not.

Main Idea:
In our prior study, a 1:10 scaled model of a three-bay gallery was illuminated by two skylights, one in Bay B and another in Bay C. To simulate colored lighting in the model, colored “filters” were placed over the skylight in Bay C. Two colored cubes were floating within Bay C, serving as the target objects; one was blue and the other was red. An observer (designated as the location of the digital camera that captured the scene) was located in Bay A. In the scaled model experiment, the red cube was placed on the left side of the observer, but for the scenes rendered with RADIANCE, the red cube was placed on

the right side of the observer (as shown in Fig. 1). The geometries of the gallery were modeled in Ecotect Analysis then exported to RADIANCE.

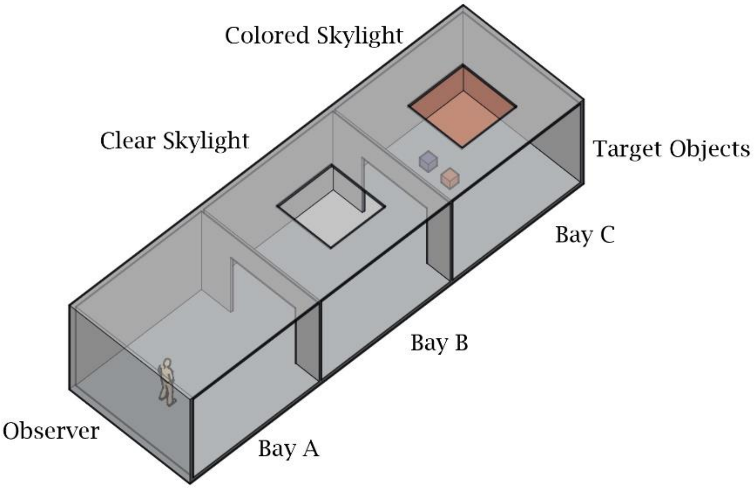

Fig. 1: Experiment scene design for the computer-simulated (RADIANCE) scenes.

In order to replicate as much as possible the colors of the scaled model in the digital environment, the colorimetric values of the materials used in the scaled model were measured using a spectrophotometer. The measured Yxy values were converted into RGB values, and then inputted as arguments for the material modifier in RADIANCE. Furthermore, the sky condition was set as CIE overcast sky, and rendering settings were left at default.

Seven lighting conditions were tested: neutral lighting (no colored filter over the skylight), and two variations each for the blue, red, and yellow colored lighting. The variations for the colored lighting were derived from the layering of filters applied in the scaled model experiment; the light variation used only one layer of colored filter, while the dark variation used four layers.

Considering that the standard display device can only display a low dynamic range, the HDR images produced by RADIANCE were tone-mapped to adequately present observers with a perceptual visual match [3]. The tone-mapped images were used as the stimuli for the psychophysical experiments, conducted to test the effect of colored lighting on color-depth perception in the three-dimensional space.

Fig. 2: Tone-mapped HDR images of the lighting conditions (From left: Neutral, Blue 1, Blue 4, Red 1, Red 4, Yellow 1, and Yellow 4 lighting).

Ten trichromat observers with normal or corrected-to-normal vision were asked to report which of the target objects in the scene appeared to be nearer under different lighting conditions. Each of the seven lighting conditions was presented ten times (at a random sequence) to the observers, which sums up to 70 trials or perceptual judgments per observer. Fig. 2 shows a compilation of the images rendered with RADIANCE (bottom row), plus the images of the scaled model (top row), to serve as comparison.

Conclusions:

Through visual inspection of the images, the most distinctive difference is the color appearances of target objects and the surround. While the hue are essentially the same, the saturation and lightness are considerably different between the scaled model images and the RADIANCE-rendered images. The colors of the targets and surround appear more saturated in the latter than the former; the RADIANCE images also look brighter overall. The altered color appearances of the objects in the scene have affected the border contrast between the target objects and the surround, and the target object that has a higher contrast with the surround was perceived to be nearer.

The results of the psychophysical experiments reveal that the observed chromostereopsis were slightly similar between the two techniques for HDR image generation, except for the Neutral lighting condition. With the scaled model image, red was perceived nearer under Neutral lighting, but for the RADIANCE image, blue was perceived nearer. It is unclear whether the cause of this change of perceiving blue to be nearer than red (called color reversal, or negative chromostereopsis) is simply due to the increased saturation and lightness in the RADIANCE images. Further experiments to acquire renderings that closely matches that of the scaled model images might require adjusting the lighting environment for the simulations or using a different approach to measure and convert the colorimetric values of the materials.

While visual inspection and statistical analysis revealed some differences in the output images and the observed chromostereopsis, the simulated images generated with RADIANCE elicited responses that correspond to images generated by radiance maps, thereby suggesting that RADIANCE can be a good alternative for creating visual stimuli for psychophysical experiments, as well as visualizing lighting design for exhibitions or installation art. Indeed, it would be interesting how a static installation art can be perceived to be dynamic just by manipulating the target-surround contrast of objects in a three-dimensional scene through colored lighting.

Acknowledgments:
We would like to thank all the people who agreed to participate in our psychophysical experiments, as well as the Ministry of Science and Technology (Taiwan), who helped support this study under Grant NO: MOST 103-2221-E-027-055-.

References:

[1] Dengler, N.; Nitschke, W.: Color Stereopsis: A Model for Depth Reversals Based on Border Contrast, Perception & Psychophysics, 53(2), 1993, 150-156. http://dx.doi.org/10.3758/BF03211725
[2] Luckiesh, M.: On 'retiring' and 'advancing' colors, The American Journal of Psychology, 29(2), 1918, 182-186. http://dx.doi.org/10.2307/1413561
[3] Reinhard, E.; Ward, G.; Pattanaik, S.; Debevec, P.: High Dynamic Range Imaging: Acquisition, Display and Image-Based Lighting (2nd Ed.), Morgan Kaufmann Publishers Inc., San Francisco, CA, 2010.
[4] Sundet, J. M.: Effects of colour on perceived depth: Review of experiments and evaluation of theories, Scandinavian Journal of Psychology, 19(1), 133-143. http://dx.doi.org/10.1111/j.1467-9450.1978.tb00313.x
[5] Thompson, P.; May, K.; Stone, R.: Chromostereopsis: a multicomponent depth effect?, Displays, 14(4), 1993, 227-234. http://dx.doi.org/10.1016/0141-9382(93)90093-K
[6] Ward, G. J.: The RADIANCE Lighting Simulation and Rendering System, Computer Graphics (Proceedings of SIGGRAPH Conference), 1994, 459-472.