VISUAL SIMULATING DICHROMATIC VISION IN CIE SPACE

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Abstract: Dichromatic vision is due to the loss of one of the three cone pigments: the L type in protanopes, the M type in deuteranopes, and the S type in tritanopes. In this paper, we show that the dichromatic vision can be simulated by applying transformation to image in CIE x, y chromaticity space. We base our work on the past experiments on unilateral color blind (color blind in one eye) people which show that for protanopes and deuteranopes the hue of 470 nm and 575 nm stimuli stay the same as that for normal eyes, and for tritanopes the hue of 485 nm and 660 nm are the same as that for normal eyes. We also assume that the curve between these anchored stimuli points and D6500 standard white stimuli in the chromaticity diagram is quadratic. Our method saves the steps for transformation of CIE chromaticity value to uniform chromaticity value or LMS value as required in the previous work and still gets reasonable results.

1 INTRODUCTION

Normal color vision is trichromatic. It is initiated by the absorption of photons in three types of photoreceptor cells in the retina: the short (S)-, middle (M)-, and long (L)-wave sensitive cones, each of which contains a different photopigment. The peak sensitivities of these three photopigments lie in the long, middle and short wavelength regions of the spectrum respectively. Therefore any color stimulus can be specified by the three cone responses.

Trichromacy, however, is not enjoyed by all. About 8% of the Caucasian male, 5% of the Asian male and 3% of the other male population suffer from color blindness or color deficiency, only 0.5% of female population is colorblind. Among colorblind population, about one quarter is dichromatic, the rest are anomalous trichromats, who have three classes of photoreceptors, but do not perceive color as normal trichromat do. Dichromacy is caused by the missing of one of the three cone pigments, of the L type in protanopes, the M type in deuteranopes, and the S type in tritanopes. Compared with trichromatic vision, dichromatic vision entails a loss of hue discrimination and results in a reduced color gamut. Dichromatic vision is a more restrictive form of defective color vision than anomalous trichromats, so that color schemes designed for dichromats can also be applied for anomalous trichromats.

In this paper, we attempt to simulate for the normal observer the color percept of dichromats. Our simulation of dichromatic vision proceeds by applying transformation in CIE x, y chromaticity coordinate space. The simulation produces plausible results.

We believe that such simulation will enable artists, web designers and graphics interface designers to check how their work will appear to color deficient people. In entertainment industry, such kind of simulation can be necessary if the synthetic character is color blind.

2 RESEARCH BACKGROUND

The history of simulation of the color perception of dichromats begins with German writer and scientist Goethe (1810). In Farbenlehre (Sharpe et al., 1999), he included a reproduction of a small watercolor that he painted to demonstrate how the landscape would appear to those lacking the blue sensation.

Although researchers can check what colors the dichromats confuse with by doing experiments, it is impossible to relate this information to what they actually see instead. This problem has been overcome

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by studying the vision of unilateral dichromats, (individuals born with one normal eye and one dichromatic eye). The past experiments suggest that both protanopes and deuteranopes see the same blue at 470 nm and the same yellow at 575 nm as trichromats (Judd, 1948; Graham and Hsia, 1958). Observations also suggest that a blue-green at 485 nm and a red at 660 nm have the same hue for the normal and tritanopic eyes (Alpern et al., 1983).

Basing on these observations, (Meyer and Greenberg, 1988) assume that color space of normal vision collapses to a line called ”major axis” on the uniform chromaticity diagram for each of the three types of dichromat. All the loci (straight lines) representing stimuli of the same dichromatic chromaticity will converge to the same point in the chromaticity diagram. That point is called confusion point and the loci passing specified stimuli and confusion point is called confusion line. Meyer and Greenberg compute replacement color seen by dichromats by calculating the intersection between the confusion line and the major axis.

(Brettel et al., 1997) propose a replacement method based on the same observations and the assumption that neutrals for normals are perceived as neutrals for dichromats. Firstly, they identify a neutral axis which is a straight line connecting origin in the LMS space and the brightest possible metamer of an equal-energy stimulus. Secondly, they represent the surface of the reduced stimuli of protanopes and deuteranopes by the two half planes anchored by neutral axis and 475-nm and 575-nm locations in the LMS space, and for tritanopes, they anchor the reduced stimuli surface by neutral axis, 485-nm and 660-nm. Finally, they compute a replacement stimulus for a stimulus in trichromatic vision by projecting it onto the half planes aforementioned by the direction parallel to the missing fundamental axis. (Viénot et al., 1999; Viénot and Brettel, 2001) simplified Brettel et al’s model by replacing the two half planes with the diagonal plane in the LMS space.

The CIE XYZ color space is based on direct measurements of the human eye, and serves as the basis from which many other color spaces are defined. The study in this paper is based on the thought that whether the simulation of dichromatic vision can be done directly on CIE x, y chromaticity values.

3 ALGORITHM

Alike the assumption of major axis in the uniform chromaticity by Meyer and Greenberg, our method assumes that the CIE chromaticity space of normal color vision collapses to a curve connecting the anchor points. The anchor points for this curve are derived from the observations discussed in Section 2. They are 470 nm and 575 nm for protanopes and deuteranopes, and 485 nm and 660 nm for tritanopes. We also assume that D6500 white stays as the same hue in normal and dichromatic vision. So the color space will collapse into a curve passing through the anchor points and D6500. We use the Lagrange interpolation to get the other points on this hue curve.

The conversion matrix to transform from CIE XYZ coordinates to RGB coordinates is known (Pharr and Humphreys, 2004):

$$[XYZ\_to\_RGB] = \begin{bmatrix} 3.2405 & -1.5372 & -0.4985 \\ -0.9693 & 1.8760 & 0.0416 \\ 0.0556 & -0.2040 & 1.0573 \end{bmatrix}$$

For a pixel in the picture, we firstly transform its RGB value to XYZ coordinates by

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [RGB\_to\_XYZ] \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

where

$$[RGB\_to\_XYZ] = [XYZ\_to\_RGB]^{-1}$$

then transform XYZ coordinates to chromaticity coordinates by:

$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z}$$

In this algorithm, we use confusion point data from (Wyszecki and Stiles, 1982):

$$\begin{array}{lll} x_p = 0.747 & x_d = 1.080 & x_t = 0.171 \\ y_p = 0.253 & y_d = -0.080 & y_t = 0 \end{array}$$

For each chromaticity point A(x,y) in chromaticity space, the chromaticity point A_p (x’,y’) actually seen by dichromats is found by intersecting the confusion line passing A with the hue curve we get by interpolation (See Figure 1).

The new chromaticity and original luminance is then transformed back to RGB space:

$$X' = \frac{Y}{y'} * x' \quad Y' = Y \quad Z' = \frac{Y}{y'} * z'$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = [XYZ\_to\_RGB] \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

If the new color fell outside the monitor gamut (the triangle in Figure 1), it is adjusted by holding its chromaticity constant and adjusting its luminance.

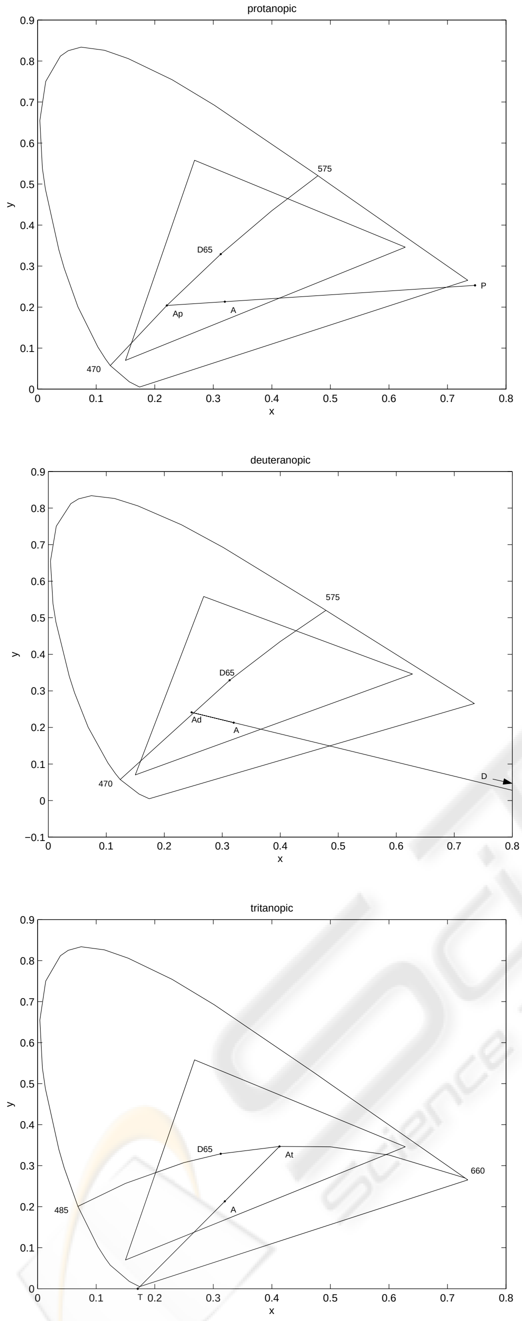
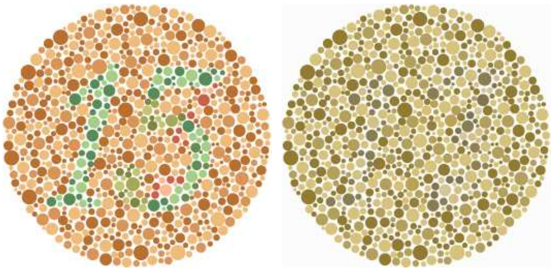
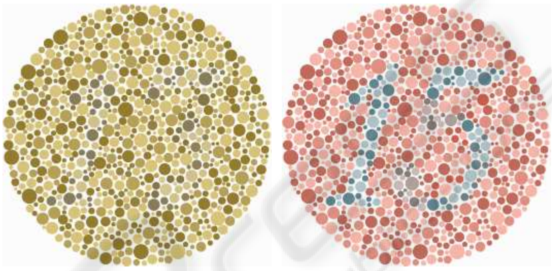


Figure 1: Curve of colors actually seen by dichromats and adjustments made to a single chromaticity point to create a dichromatic version of image. D65 represents D6500 white and the triangle is the monitor gamut. Point P, D and T are confusion points and the straight lines decided by confusion points and A are confusion lines. A_p, A_d, A_t are the chromaticity points actually seen by protanopes, deuteranopes and tritanopes on point A.

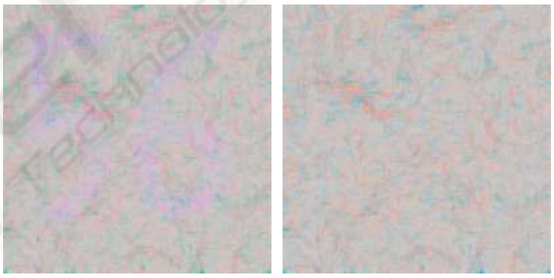


(a) Normal (b) Protanopic



(c) Deuteranopic (d) Tritanopic

Figure 2: Dichromatic versions of a testing image.



(a) Normal (b) Tritanopic

Figure 3: Tritanopic version of a testing image.

4 RESULTS

We implemented the algorithm in MATLAB. The program takes the type of dichromat and a color image as input, and generates as output an image for the specified dichromat. We present the results of our algorithm for standard images used for colorblindness testing. In Figure 2, the original Ishihara test image from Colorblind homepage (http://www.colorvisiontesting.com/) is transformed to protanopic and deuteranopic images where ”15” in the normal version is recognized as ”13” or nothing. Figure 3 shows an image from Wikipedia website (http://en.wikipedia.org/wiki/Color_blindness) used for testing tritanopia and its appearance in the tritanopic vision generated by our algorithm.

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A colorful picture and its appearance in dichromatic vision are shown in Figure 4.

5 DISCUSSION

To compare our algorithm and the previous work, we run a test to convert the image in Figure 4(a) to protanopic version using this algorithm, our implementation of Meyer's algorithm and Brettel's algorithm. The resulting images are shown in Figure 5. The test is done on a PC with a CPU of 2.00 GHZ AMD Athlon XP 2400+ and 512 Mb memory. The elapsed time for our algorithm, Meyer's algorithm and Brettel's algorithm are respectively 87.5 s, 94.0 s and 117.4 s. Our algorithm is more efficient because it does not require the procedure to transform color value from CIE XYZ space to uniform chromaticity value or LMS value as in Meyer or Brettel's work.

6 CONCLUSION AND FUTURE WORK

In this paper, we show that the simulation of dichromatic vision can be done by simple transformations in CIE x, y chromaticity space. Our method saves the steps for transformation of CIE chromaticity value to uniform chromaticity value or LMS value as required in the previous work and still gets reasonable results. (Wachtler et al., 2004) propose that the color appearance in dichromatic vision is richer than was previously thought. They insist that previous linear color vision models fail to account for the richness of color experience that dichromats enjoy and express. They also propose a nonlinear model to simulate hue scaling results. Using their model for realistic rendition of dichromatic vision will be an interesting future work.

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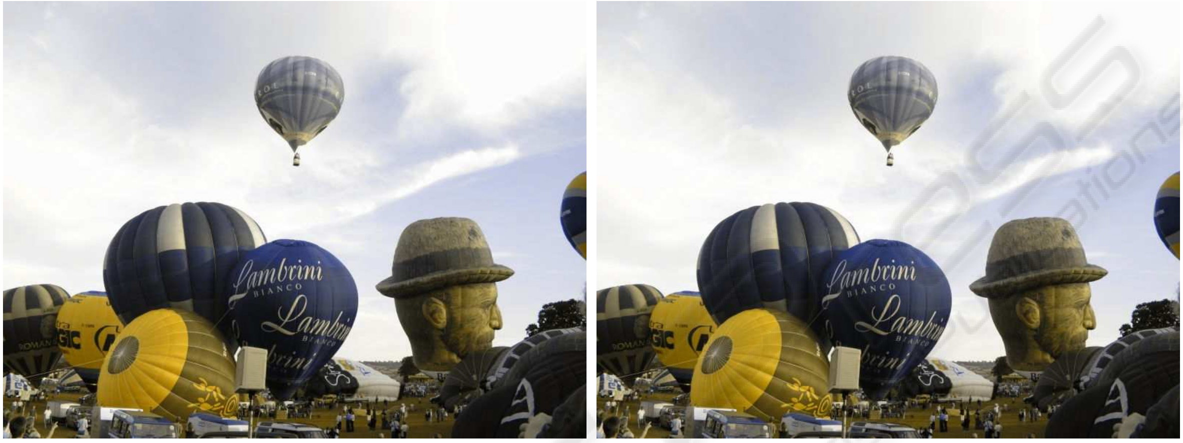
(a) Normal (b) Protanopic

(c) Deuteranopic (d) Tritanopic

Figure 4: A colorful picture and its appearance in dichromatic vision.



(a) Our algorithm (b) Meyer's algorithm

(c) Brettel's algorithm

Figure 5: The protanopic results of our algorithm and other algorithms applied on Figure 4(a).