BICHROMATIC PLATES SYNTHESIS FOR TESTING DICHROMATS

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ABSTRACT

Pseudoisochromatic plates are among the most popular tests for color visual deficiency(CVD), which are often time printed using a circle of dots appearing randomized in color and size. They are particularly good for screening but are less good in assessing the degree and type of the CVD due to the inappropriate use of color combination and fixed pattern in currently available pseudoisochromatic tests. In this paper, we present a method to synthesis a sufficient number of diagnostic plates only with color matches carefully selected among perceptual color space. To select the acceptable color matches, we assume that Brettel et al.s simulation model is qualitatively correct, which can be used to compute the corresponding pair of arbitrary given color with respect to three type of dichromacy. Then we use color difference as distance metric to learn whether a pair of candidate colors is confused by dichromats but normal vison. By the obtained color sets, pseudoisochromatic samples are colorized in which random digital integers 0 9 are used as foreground. The simulation results show not only the color pairs of colors lie upon appropriate isochromatic lines but the luminance contrast between the two colors be kept within reasonable interval.

***Index Terms*—** Color vision deficiency, dichromacy, color difference, pseudoisochromatic plate, corresponding pair

1. INTRODUCTION

Color visual deficiency(CVD), also called color blindness, represents a group of conditions that affect the perception of color. Normal color is trichromatic, which is the result of three different types of cone photoreceptors [1]. Individuals who lack one type of cone photoreceptor are called dichromats, more specifically, protanopes, deuteranopes, and tritanopes, each of which have their own specific color confusion characteristics. Because color perception is a subjective experience, it is difficult for normal people to imagine the colors that dichromats see, which originate from the responses of the two remaining types of cone photoreceptors. In order to understand the color appearance in dichromats,many of digital simulation methods have been developed [2, 4, 5], in which the main point is to alter images using a model of CVD in order to show trichromats what the image looks like to dichromats.what the image looks like to dichromats. Brettel et al. have revised a most notable computerized algorithm to simulate for the normal observer the appearance to the dichromat of any digitized image. In fact, the simulated image of dichromats by Brettel et al.s model [3] is used to reproduce color appearances of dichromats. In this paper, we adopt this model reversely to search pseudoisochromatic color pairs and check whether dichromats can discriminate one color from another given in an bichromatic image. We define two categories of pseudoisochromatic color with color difference [7, 8] as a similarity metric.

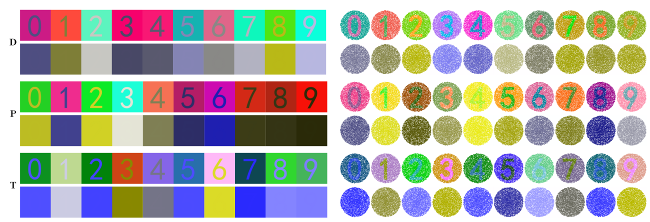

Fig. 1. Pseudoisochromatic samples and the dichromatic simulation results. Each of two rows from top to bottom are synthetic samples and their simulation with respect to derternopia, protanopia, and tritanopia. This figure should be viewed in color. We also encourage readers to print it on grayscale printer and compare the content visibility with the original one. That is to say, these kind of images are challenging to both dichromats and color2gray algorithms.

For test the color vision, the Ishihara plates were revised a century ago with the concept of pseudoisochromaticism, enabling researchers and optometrists to acquire qualitative data about patients with color visual defect [9, 11, 12]. The test consists of a number of colored plates, each of which contains a circle of dots appearing randomized in color and size. Within the pattern are dots which form a number or shape clearly visible with normal color vision and invisible, or difficult to see, to those with color vision defect, vice versa. Since creation, the Ishihara Blindness Test has become commonly used worldwide because of its easy use and high accuracy. However, improved revising methods for more accurate diagnostic plates are required due to the inappropriate use of color combination and fixed pattern.

In this paper, pseudoisochromatic samples are synthesized with bichromatic manner of two styles shown as fig.1 above. We assume that the dichromatic color appearance of Brettel et al. [3] is qualitatively correct, which can be adopted to compute the corresponding pair of arbitrary given color, as well as to obtain the simulation results. Digital number in each sample can be distinguished by only trichromats but the targeted dichromats. To search the confused color, CIE 1976 (L*a*b) color difference formula [8] is adopted to measure the distance of given colors and set as threshold for sampling among perceptual color space. For simplicity, the bichromatic plates are synthesized for each type of dichromats, with digital integers 0-9 as foreground. The simulation results are obtained again using the Brettel et al.s model.

This paper have two main contributions: 1) Definition of two categories of pseudoisochromatic color pairs as confused color pairs and identical color pairs, both with a specific formula and experimentally analysis of distribution among RGB color space. 2) Synthesis of pseudoisochromatic plates. The resulting samples show our method have the potential for accuracy evaluation of CVD in practice.

2. METHODS

Since the confused color pairs in the perceptually uniform color space is finite, we use a first sample and selection procedure. The color pair searching algorithm is a 3 step process. Firstly, we sample among the color space using a grid with uniform step length. Secondly, we use the Brettel et al.s simulation model to get the corresponding pairs of sampled colors. Thirdly, set the color difference threshold with respect to sampled colors and their corresponding pairs for color selection.

To make our method explicit, we represent initial color stimuli as vectors in three-dimensional RGB space. The color matches are categorized into two types, namely confused color pairs, and identical color pairs, both of which from the corresponding pairs defined below.

2.1. CVD simulation and the corresponding color pair

To make someone with normal vision feel intuitively how dichromats experience colors, Brettel et al. proposed a simulation method to convert arbitrary color to its corresponding pair. The simulation algorithm is a three step process. Given arbitrary color in RGB color space as vector:

$$Q=\begin{pmatrix} R_Q \\ G_Q \\ B_Q \end{pmatrix}$$

Firstly, convert the RGB input to a LMS color space:

$$\begin{pmatrix} L_Q \\ M_Q \\ S_Q \end{pmatrix} = \mathrm{T} \begin{pmatrix} R_Q \\ G_Q \\ B_Q \end{pmatrix}$$

where $T = \begin{bmatrix} L_R & L_G & L_B \\ M_R & M_G & M_B \\ S_R & S_G & S_B \end{bmatrix}$ is the transform Matrix from RGB to LAB color space. Secondly, apply the Brettel et al.s simulation in LMS color space to get the reduced LMS color for target type of dichromats:

$$\begin{pmatrix} L_{Q^\tau} \\ M_{Q^\tau} \\ S_{Q^\tau} \end{pmatrix} = {T_{sim}}^\tau \begin{pmatrix} L_Q \\ M_Q \\ S_Q \end{pmatrix}$$

where ${T_{sim}}^\tau$ is the simulation matrix for dichromats, τ is a value in list $[d, p, t]$, and each value of the list represent each type of dichromats, namely deuteranopia, protanopia, and tritanopia. Finally, get the corresponding pair Q^τ by converting the reduced LMS color back to RGB space using a reverse transformation:

$$Q^\tau = \begin{pmatrix} R_{Q^\tau} \\ G_{Q^\tau} \\ B_{Q^\tau} \end{pmatrix} = \mathrm{T}^{-1} \begin{pmatrix} L_{Q^\tau} \\ M_{Q^\tau} \\ S_{Q^\tau} \end{pmatrix}$$

Then we say the Q^τ is the corresponding pair of Q. For simplicity, we define overall process into one step function:

$$Q^\tau = f_{\mathrm{sim}}\,(\mathrm{Q};\tau)$$

in which f_{sim} contains three steps of transformation mentioned above, and returns the corresponding pair Q^τ of given RGB color Q with respect to dichromatic type τ.

2.2. CIE L*a*b* 1976 Color difference formula

For many years, many researchers have undertaken work to deduce the color difference for complex image. CIE L*a*b* is a color space specified by international Commission On Illumination which describes all the colors visible to human eye. There is no simple formula for conversion between RGB and L*a*b*, because RGB color models are device dependent. In order to measure color difference in perceptual space, the RGB vector is converted uses a two-step calculation process. To convert the RGB input to a perceptually uniform CIE L*a*b* color space, we firstly convert the RGB vector Q to CIE XYZ color space as follow:

$$\begin{pmatrix} X_Q \\ Y_Q \\ Z_Q \end{pmatrix} = BQ = \frac{1}{b_{21}} \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{pmatrix} R_Q \\ G_Q \\ B_Q \end{pmatrix}$$

in which the coefficients in the conversion matrix above are exact and specified in CIE standards. Secondly, do a CIE

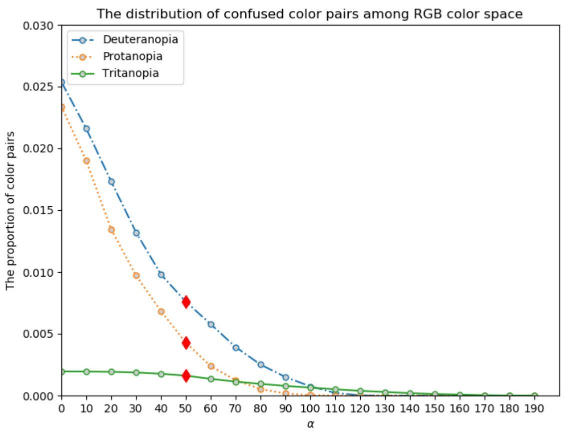

Fig. 2. The distribution of confused color pairs. It shows us the confused color pairs we define are rare, especially for the type of tritanopia. Since we sample among the RGB space using $8 \times 8 \times 8$ grid, it iterate over most of the representative colors. The key points marked with red diamond are chosen for later experiment where $\alpha = 50$.

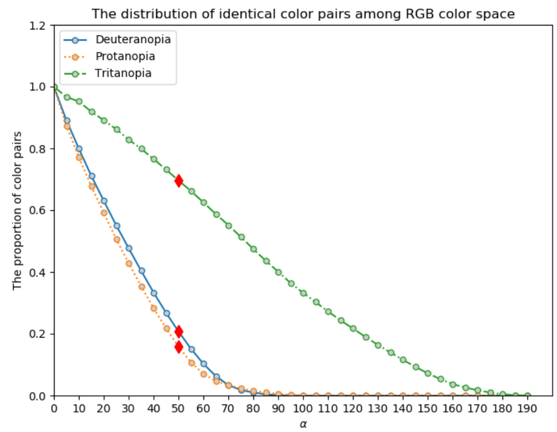

Fig. 3. The distribution of identical color pairs. Compared with Fig. 2., the proportion of identical color pairs is relatively larger. We also set the $\alpha = 50$ for experiment, in which condition the identical color pairs for each type is sufficient as marked in red diamond.

XYZ to CIE L*a*b* conversion as follow:

$$L* = 116 f\left(\frac{\mathrm{Y}}{Y_n}\right) - 16$$

$$a* = 500\left(f\left(\frac{X}{X_n}\right) - f\left(\frac{\mathrm{Y}}{Y_n}\right)\right)$$

$$\mathrm{b}* = 200\left(f\left(\frac{\mathrm{Y}}{Y_n}\right) - f\left(\frac{Z}{Y_n}\right)\right)$$

where $X_{\mathrm{n}}, Y_{\mathrm{n}}, \mathrm{Z}_{\mathrm{n}}$ are CIE XYZ tri-stimulus values of the reference white point. Under the Illuminant D65 standard with normalization $T = 100$, the values are:

$$X_{\mathrm{n}} = 95.047, Y_{\mathrm{n}} = 100.000, \mathrm{Z}_{\mathrm{n}} = 108.883$$

And then, the CIE L*a*b* 1976 color difference can be calculated by:

$$\begin{aligned}&\Delta E*_{\mathrm{ab}}(Q_1, Q_2) = [(\Delta L*)^2 + (\Delta \mathrm{a}*)^2 + (\Delta b*)^2]\\ &= [(L_{Q_1}* - L_{Q_2}*)^2 + (\mathrm{a}_{Q_1}* - \mathrm{a}_{Q_2}*)^2 + (b_{Q_1}* - b_{Q_2}*)^2]\end{aligned}$$

where Q_1, Q_2 are given RGB vectors. The value of $\Delta E*_{ab}$ is a scalar represents the distance between Q_1 and Q_2.

2.3. Confused color pairs

In this paper, we define Q_1, Q_2 as the confused color pairs for dichromatic type τ, if and only if they satisfy the following conditions:
$\begin{cases} \Delta E*_{\mathrm{ab}}(Q_1, Q_2) > \alpha \\ \Delta E*_{\mathrm{ab}}({Q_1}^{\tau}, {Q_2}^{\tau}) < \beta \end{cases}$,where α, β are the constraints, also can be regard as threshold for color selection. For this non-homogenous linear inequalities, due to the irreversibility of the coefficient matrix in f_{sim}, we can hardly predict Q_2 given Q_1 by estimating the approximate solution. Since the RGB color space is finite with each components range from $(0, 255)$, we can sample the whole color space with a grid of $n \times n \times nusinguniformstride\lambda$. With a suitable n and λ, the sampled items can represent all the distinguishable colors in the RGB color spaces. We used a grid of $n = 8$ with stride $\lambda = 12$ to sample over 2×8^3 colors to search for the color pairs. Since the computation complexity with multiplier 2×8^3 is reasonable and mild. Let each of $i, j, k \in [0, 7] \in Z^+$, we sample Q_1, Q_2 as:

$$Q_1 = \begin{pmatrix} R_{Q_1} \\ G_{Q_1} \\ B_{Q_1} \end{pmatrix}, \text{with} \begin{cases} R_{Q_1} = 32i + 2 \\ G_{Q_1} = 32j + 14 \\ B_{Q_1} = 32k + 26 \end{cases}$$

$$Q_2 = \begin{pmatrix} R_{Q_2} \\ G_{Q_2} \\ B_{Q_2} \end{pmatrix}, with \begin{cases} R_{Q_2} = 32i + 6 \\ G_{Q_2} = 32j + 18 \\ B_{Q_2} = 32k + 30 \end{cases}$$

For each Q_1, Q_2, we have the corresponding color pairs: ${Q_1}^{\tau} = f_{\mathrm{sim}}(Q_1;\tau), {Q_2}^{\tau} = f_{\mathrm{sim}}(Q_2;\tau)$. To set $\beta = 10$, let $\alpha = 10\Phi, \Phi \in [0, 40], \Phi \in Z^+$, we can obtain the distribution of the confused color pair with respect to each τ in RGB color space as shown in Fig. 2.

2.4. Identical color pairs

As the simulation is based on color confusions exhibited by dichromats, and the simulation itself is a reduced mapping, there should be some colors appear identical to dichromats

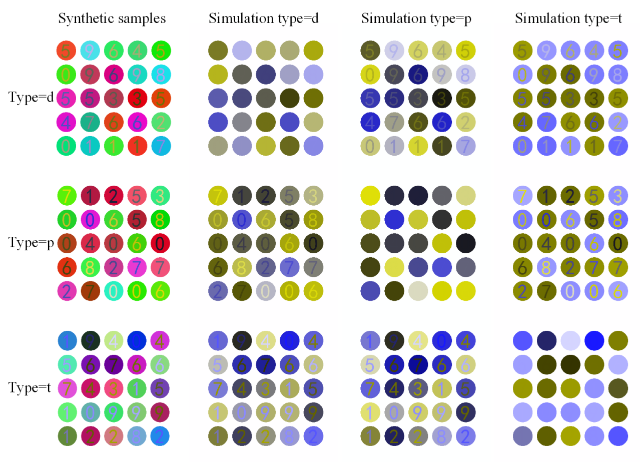

Fig. 4. Synthetic samples by identical color pairs. In the process of identical color pairs selection, we ensured that each colors appear above have different RGB values. The content visibility of each samples is diminished after targeted simulation.

but the normal vision. That is to say, the dichromats should not notice any difference between the original color and the simulated color corresponding to their deficiency. We define these kind of color pairs mapped to the same corresponding color as identical color pairs, which can be obtained with the following simulation property:

$$(Q^{\tau})^{n} = f_{\mathrm{sim}}{}^{n}\,(Q;\tau) = Q^{\tau}\mathrm{n} \geq 2$$

where $(Q^{\tau})^{n}$ means to simulate the given color Q for n times. The simulation of simulated color can be regard as identical transform. Further, we can infer that, given arbitrary Q, there is:

$$\Delta E*_{\mathrm{ab}}(Q, Q^{\tau}) = \alpha \geq 0$$

$$\Delta E*_{\mathrm{ab}}(Q^{\tau}, (Q^{\tau})^{2}){=}\Delta E*_{\mathrm{ab}}(Q^{\tau}, Q^{\tau}) = \beta = 0$$

Thus we can use this deduction directly to sample identical color pairs among the corresponding color pairs. To sample over the whole RGB color space, we use a grid of $n = 32 and spread 32^{3}$ candidate colors. Let $i, j, k \in [0, 31] \in n$:

$$Q{=}\begin{pmatrix} R_Q \\ G_Q \\ B_Q \end{pmatrix}, with \begin{cases} R_Q = 8i + 2 \\ G_Q = 8j + 4 \\ B_Q = 8k + 6 \end{cases}$$

Since $\beta = 0$, let $\alpha = 5\Phi, \Phi \in [0, 40], \Phi \in Z^{+}$, we obtain the distribution of the identical color pairs with respect to each τ in RGB color space. The result is showed shown in Fig. 3.

3. EXPERIMENTAL RESULTS

Let $\alpha = 50$, we obtained sufficient number of both identical and confused color pairs for image synthesis. For simplicity, we use simple digital integers 0 9 to construct the foreground, and colorized with only pseudoisochromatic pairs for

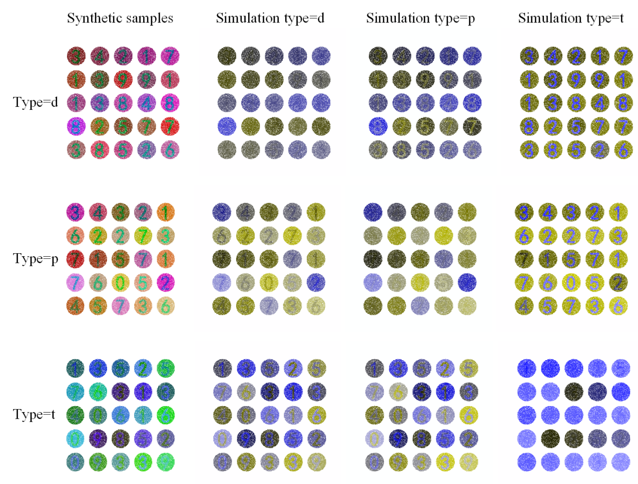

Fig. 5. Synthetic samples by identical color pairs(Better to view with zoom in). A few plates remain visible partly due to the visual retention and higher contrast.

each plate. To evaluation, we randomly picked up every 5×5 samples from each type of synthetic plates to and simulated as a whole image using algorithms of three type of dichromats.

For plates colorized with identical color pairs, we did color filling in a direct manner. The result is shown in Fig. 4., in which we can see that after type-specific simulation the foreground is totally disappeared from the view. According to the Brettel et al. model, qualitative judgement of vision condition can be made by identifying the content among these pictures.

For confused color pairs, direct color filling may not reasonable since the color difference between them is tiny but still noticeable. Thus we borrowed the same method from the Ishihara plates, that is, to draw circles of random size while preserving the content visibility for normal vision as shown in the Fig. 5. And also, the content is perfectly hidden only after the simulation of the targeted defect type.

4. CONCLUSIONS

We have explored the pseudoisochromatic color pairs and proposed a procedure to synthesize test plates for dichromats. The resulting plates are available online as a dataset for pseudoisochromatic plates, which are splited into three subsets. Due to the existing difficulty in finding adequate color-deficient subjects for evaluation, this work cannot yet put in practice. Considering that precision of such simulation models remain uninvestigated [6], further effort is still needed for future.

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