A Study on Color Conversion for Color Deficient People to Identify Color

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Abstract. The sensitivity of the M-cones and L-cones of an anomalous trichromat is lower than that of normal trichromats. By intensifying the light to the cones with lower sensitivity, the output ratio from the cone approached the level of a normal trichromat, and it was presumed that achieving close to original color recognition was a possibility. In order to increase luminous intensity, in the LMS space, the boundary was set as the plane surface representing pseudoisochromatic color, and the distance from that plane was expanded. When making large changes in light intensity near the surface representing pseudoisochromatic color, improvements in color differentiation and degree of color identification were observed. We plan to implement this method in mobile devices and to evaluate the experimentation results.

1 Introduction

In recent years, large amounts of information containing color information are being transmitted. In many cases, this color information contains important messages or brings attention to the importance of information. The color-blind are unable to receive color information accurately. 5% of Japanese males (around 3 million), and 8% of Caucasian males, have what is called “red-green color blindness,” in which color differentiation becomes difficult for color ranges containing red or green [3].

What are the options to address the issues arising from color-blindness? One is for those transmitting information to take action in consideration of those who are color blind. The other is for the color-blind to take action on the receiving end. This paper deals with the latter option. Methods to increase color differentiation for anomalous trichromats will be considered, as well as observation of changes in perception of images occurring as a result, and methods to decrease the difficulty of color identification.

2 Background

Color recognition, the process of how color-blindness develops, and the simulation method for color-blind image perception will be explained.

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2.1 Color Recognition

Color is not a quality of matter, but a sensation created by the brain based on the wavelength and intensity information received by the eye. Light in the range of 360nm - 830nm can be recognized as color. Light with varying wavelengths are recognized as different colors. Light at 540nm is recognized as the color green, 580nm yellow, and 660nm as red. When light at 540nm and at 660nm is mixed, the light is recognized as yellow. Our recognition is not distinguishing differences in physical properties of light [2] [4].

Photoreceptor cells are divided into rods and cones. Depending on the intensity of available light, rods mainly function in relatively low light environments, and cones function mainly in brighter environments. Cones are divided into S (Short) cones, M (Middle) cones, and L (Long) cones. The wavelength in which each type of cone responds is different and depends on the quality of the visual pigment inside the cone. S-cone (blue cone) has blue visual pigment (absorption maximum wavelength 419nm), M-cone (green cone) has green visual pigment (absorption maximum wavelength 531nm), and L-cone (red cone) has red visual pigment (absorption maximum wavelength 558nm). Each cone responds through the visual pigments depending on the wavelength element of the light entering the eye.

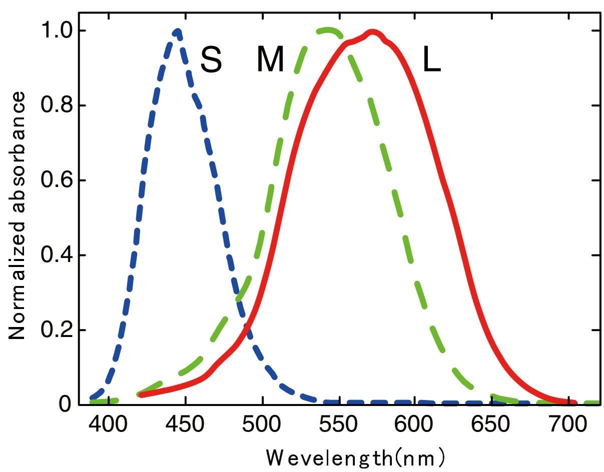

Fig. 1. Normalized responsively spectra of human cone cells, S, M, and L types

2.2 The Process of Color-Blindness Development

When mutation occurs in the visual pigment genes, visual pigments cease to exist or the qualities of visual pigments change radically. This results in dichromacy or anomalous trichromacy.

Mutation of red visual pigment is called protonomaly; mutation of green visual pigment deutronomaly, and mutation of blue visual pigment is called tritanomaly. Out of Japanese males, 1.5% has protonomaly, 3.5% has deutronomaly, and 0.001% has tritanomaly.

The red and green visual pigments have overlapping absorption spectra. If there is a problem in either, color differentiation becomes difficult in the red through green range, and thus is called "red-green color-blindness." In third color-blindness, the color difference in the yellow through blue wavelength range becomes difficult to recognize and thus is called "blue-yellow color-blindness."

2.3 Color-Blindness Simulation

The method used on normal trichromats to simulate color-blindness is explained [1] [5].

The RGB value of each pixel in an image is converted to the amount of LMS stimulation received by the 3 types of cones. After compensation, the RGB value is re-calculated to create the compensated image.

Equation 1 is color stimuli Q.

$$Q = (L_Q, M_Q, S_Q) \tag{1}$$

Color stimuli Q are determined by the amount of each wavelength included in the original light. The original light spectra distribution is expressed as $\varphi_q(\lambda)$, the spectral sensitivity function of each cone as $\bar{l}(\lambda)$, $\overline{m}(\lambda)$, $\bar{s}(\lambda)$, k is a constant determined to complete Eq. 2. Color stimuli Q are expressed in Eq. 3.

$$L_Q + M_Q = 1 \tag{2}$$

$$\begin{aligned} L_Q &= k\int \varphi_Q(\lambda)\bar{l}(\lambda)d\lambda \\ M_Q &= k\int \varphi_Q(\lambda)\overline{m}(\lambda)d\lambda \\ S_Q &= k\int \varphi_Q(\lambda)\bar{s}(\lambda)d\lambda \end{aligned} \tag{3}$$

P_R, P_G and P_B are the colors produced when RGB values are maximized on a monitor. The $\varphi_R(\lambda)$, $\varphi_G(\lambda)$ and $\varphi_B(\lambda)$ are measured at that time, and L_i, M_i and S_i $(i = R, G, B)$ are found with Eq. 3. Table 1 shows the results.

Table 1. LMS tristimulus values for the red, green, and blue primaries

	$i=R$	$i=G$	$i=B$
L_i	0.1992	0.4112	0.0742
M_i	0.0353	0.2226	0.0574
S_i	0.0185	0.1231	1.3550

Q, the color displayed on the monitor is expressed in Eq. 4.

$$Q = (R_Q P_R + G_Q P_G + B_Q P_B) \tag{4}$$

R_Q, G_Q and B_Q are a number greater than 0 and less than 1.

The method of converting RGB values to stimulation values LMS are shown below. The original color V is Eq. 5.

$$V = \begin{pmatrix} R_Q \\ G_Q \\ B_Q \end{pmatrix} \tag{5}$$

Eq. 6 is the conversion matrix T using the values in table 1.

$$T = \begin{pmatrix} L_R & L_G & L_B \\ M_R & M_G & M_B \\ S_R & S_G & S_B \end{pmatrix} \tag{6}$$

Q is expressed in Eq. 7.

$$Q = TV \tag{7}$$

Q is adjusted according to the color-blind user as Q'. Using Eq. 8, V' corresponding to the color stimuli Q' recognized by the color-blind user is found. V' is used to create the compensated image.

$$V' = T^{-1}Q' \tag{8}$$

3 Proposal

Anomalous trichromacy is between normal trichromacy and dichromacy. Anomalous trichromats have lower M and L-cone sensitivity compared to normal trichromats. Only the light wavelengths responding to M or L-cone from the original image are intensified. By intensifying the light wavelengths where sensitivity was low, the reaction ratio of the cone approaches that of normal trichromats, and possibly causes color recognition similar to that of normal trichromats.

Using the method stated in the color-blindness simulation, the RGB of each pixel is converted to LMS and intensified in the axial L and M direction. The boundary was set as the plane surface representing pseudoisochromatic color, and the coordinates greater in comparison were emphasized more, while coordinates smaller in comparison were emphasized less. The overall distance between each coordinate and the plane surface representing pseudoisochromatic color is made larger. By doing so, it is presumed that the color recognition of the anomalous trichromat can be changed from a state close to dichromacy, to that of a normal trichromat.

3.1 The Emphasis Range

The method used for color-blindness simulation is used for the given color stimuli Q, the point on the planar surface representing pseudoisochromatic color is found, and this value is set as 0. If intensifying in the M axis direction, L and S are fixed while M is changed. If intensifying in the L axis direction, M and S are fixed while L is changed. If in the M axis direction, the largest M value is set as 1 in the reproducible monitor range, and if in the L axis direction, the largest L value is set as 1. Normalization is conducted so that the plane surface representing pseudoisochromatic color becomes 0, and the largest reproducible value is 1. Normalization is also conducted so that the smallest reproducible value becomes 1.

The plane surface representing pseudoisochromatic color spreads beyond the reproducible monitor range. It is possible that when intensifying in the M axis direction from a given value, the result is beyond the reproducible range. When this happens, given that the plane surface representing pseudoisochromatic color is 0, there are 2 possibilities. Either, both the largest possible value and the smallest value of the reproducible range are both lined up greater than 0, or, conversely, they are both lined up less than 0. In this situation, the one farther from the plane surface representing pseudoisochromatic color is set as 1. The distance between the ignored point and the plane surface representing pseudoisochromatic color is an irreproducible range, and thus it is impossible for that value to be obtained from the original image.

3.2 Calculation Method of Color Stimuli Q'

LMS is converted to find Q'. The 3 conversion methods are shown below.

(a) The original large-small relationship is maintained in the axis direction.
(b) Changes are not made at the 0 point.
(c) Containment within the monitor reproducible range.

In this paper, the functions shown below Eq. 9 are used to find the emphasis range.

$$f(x)=\begin{cases}(1+20a)x & (0\le x\le 0.05)\\ x+a & (0.05\le x\le 0.95)\\ (x+20a)/(1+20a) & (0.95\le x\le 1\end{cases} \tag{9}$$

Eq. 9 is used to find Q' from Q.

4 Experiment

Color blind subjects were used for the test. The test subjects were shown the 1 original image and converted image, and color recognition was tested.

4.1 Experiment

Differentiation and impression was tested. The test subjects were shown a photo, image converted from an original image. The following were tested for the test subjects.

- Ease of color differentiation
- Whether the converted image retains the impression of the original image

(a) Original Image (b) Converted Image

Fig. 2. The original image and the color converted image

4.2 Results of Experiment

- Dichromats did not feel any difference between the converted image and the original image.
- Anomalous trichromats felt an improvement in ease of color differentiation for converted image.

5 Discussion

The effectiveness of the proposed method will be discussed based on the results.

5.1 Difference in Effectiveness, by Type of Color Blindness

The proposed method was intended for anomalous trichromats and the possibility of there being no positive effects on dichromats was expected. Based on the results from experiment 3, the method is ineffective for dichromacy.

In the survey answers from dichromats, some answers suggest that they recognized the changes between the converted image and the original image. Further study is needed to verify these claims.

From the results of experiment, the method had positive effects for anomalous trichromats. However, further study is needed regarding the conversion methods.

5.2 Evaluation of the Conversion Method

By using the proposed method, anomalous trichromats were able to feel a difference in the color of the original image and the converted image.

Three test subjects felt an improvement in both ease of color differentiation and color identification for converted image.

6 Application for Mobile Devices

Recently, mobile devices are often equipped with a digital camera and color display. We are implementing technology that would allow the color blind user to take a picture of the image he would like to see, convert the image, and view it on the display of his mobile device. We plan to evaluate the color conversion application implemented on a mobile device.

7 Conclusion

The cone of the anomalous trichromat has low sensitivity; however, by intensifying the color stimuli, there was a response, like a normal trichromat cone. As a result, improvements were observed in ease of color differentiation and level of color differentiation.

8 Future Issues

There are also large differences in the cones of individuals. Especially in anomalous trichromacy, there is great variation, and this can possibly result in minute variations of recognition. Therefore, genetic variance needs to be considered. A system where the color blind can choose parameters that meet their needs, or a system that adapts to the needs of the color blind is needed.

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