Color Enhancement for the Colorblind Using Color Correction Intensity Map and Pix2pix Image Conversion

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***Abstract*—In this paper, we propose a method for creating easy-to-see images by estimating regions where color discrimination is difficult for people with color blindness and performing color correction. There are various prior studies on color correction of images for the colorblind. However, in many cases, the goal is only to identify text or objects, and thus the hue of the image is often unnatural compared to the original image. To solve this problem, we estimated the color discrimination gap between colorblind and normal subjects based on confusion loci theory, and performed color correction using the pix2pix model. The aim is to prevent unnecessary hue changes by estimating the correction intensity, and to achieve highly accurate color correction by deep learning. From the validation using a colorblindness simulator, we obtained the result that color discrimination becomes easier for colorblind people while maintaining the hue close to that of the original image. This method allows easy color correction of existing images for the colorblind without any loss of hue.**

I. INTRODUCTION

Photoreceptor cells in the human eye are classified into three types according to their sensitivity to light wavelengths[1], [2]. S-cone cells respond to blue, M-cone cells to red, and L-cone cells to green. We perceive colors according to the relative ratio of the excitations of these three types of cones. When one of the photoreceptor cells is damaged or loses its function, either by birth or later in life, we receive only a part of the spectral information of light, limiting the colors we can perceive. 8% of white men, 4% of black men, and 5% of yellow men have color vision characteristics that make it difficult to perceive a specific range of colors. As an example, a person who lacks L-cone function is called Protanope and cannot distinguish between red and green. Those lacking M-cones are called Duteranope, and those lacking S-cones are called Tritanope. These color-vision characteristics may cause inconveniences such as difficulty in reading letters and signs in certain color combinations. Therefore, colorblind people need assistance to distinguish colors more effectively.

A solution to this problem is to adjust the color contrast using aids such as color vision aids such as spectacles, but there are problems such as the time of professional testing and physical constraints Another method is color correction of images by image processing. This method requires no inspection and has a wide range of applications. Huang[3] proposed a color correction method based on mapping by the relationship between color blindness images and normal images. Dody[4] proposed a color correction algorithm for color deficient images using RGB color clusters and graph coloring.

Most color correction algorithms are only intended to help colorblind people distinguish colors. Therefore, the corrected images are unnatural for normal people, for example, a red flower becomes blue. In addition, there is a problem that color correction is applied to the background color, which changes the saliency of the image. To solve this problem, we propose an estimation of correction intensity based on confusion loci theory and color correction by pix2pix. The present study will focus Duteranope, which has the highest percentage of color blindness. In our method, the color components of an image that are difficult for colorblind people to distinguish are estimated for each pixel, and the intensity of color correction is estimated. Next, a color-corrected image is generated using a pix2pix model that has been trained to learn color corrections that are easy for colorblind people to distinguish. Then, the original image and the corrected image by pi2xpix are blended using the color correction intensities. By using the color correction intensity, saliency is preserved and unnecessary coloring is prevented. Pix2pix model allows natural color correction by referring to the color scheme of the original image rather than a random color scheme.

II. RELATED WORKS

A. Simulation of color blindness(Duteranope)

The spectral sensitivity values of human L, S, M-cones can be obtained from the CIE-1931XYZ, as follows:

$$\begin{pmatrix} L \\ S \\ M \end{pmatrix} = \begin{pmatrix} 0.40024 & 0.70760 & -0.08081 \\ -0.22630 & 1.16532 & 0.04570 \\ 0 & 0 & 0.91822 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad (1)$$

From Brettel's formula[5], assuming LSM cone response values as L_d, M_d, S_d, the color vision of Duteranope is expressed

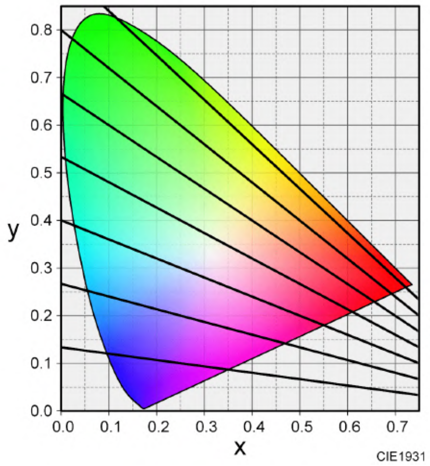

Fig. 1: Confusion loci in xy chromaticity diagram (Duteranope vision)

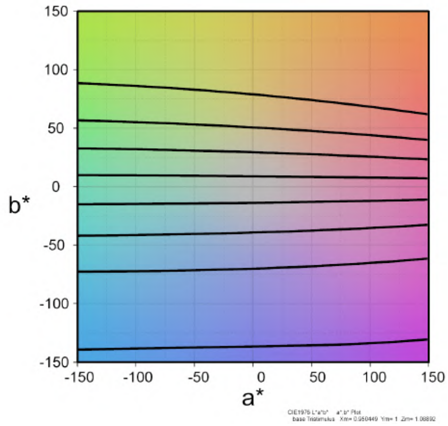

Fig. 2: Confusion loci in a^*b^* chromaticity diagram (Duteranope vision)

as follows

$$\begin{cases} \begin{pmatrix} L_d \\ S_d \\ M_d \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0.82781 & 0 & 0.17216 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} L \\ S \\ M \end{pmatrix} & \text{if } S \leq L \\ \begin{pmatrix} L_d \\ S_d \\ M_d \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0.81951 & 0 & 0.18046 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} L \\ S \\ M \end{pmatrix} & \text{if } S \geq L \end{cases} \tag{2}$$

By using the inverse matrix of equation (3) for L_d, S_d, M_d, we can obtain the pixel values X_d, Y_d, Z_d, Duteranope vision in XYZ.

$$\begin{pmatrix} X_d \\ Y_d \\ Z_d \end{pmatrix} = \begin{pmatrix} 1.85995 & -1.12939 & 0.21990 \\ 0.36119 & 0.63881 & 0 \\ 0 & 0 & 1.08906 \end{pmatrix} \begin{pmatrix} L_d \\ S_d \\ M_d \end{pmatrix} \tag{3}$$

By converting X_d, Y_d, Z_d to RGB, it is possible to create a simulated image of color blindness.

B. Confusion Loci Theory

Colorblind people have coordinates called confusion centers at different locations on the xy chromaticity diagram, depending on the type of color vision characteristic. The coordinates of the confusion center for Duteranope obtained by Judd[6] are $x_d = 1.000, y_d = 0.000$. From these coordinates, a myriad of lines can be drawn, each of which is a confusion loci for each color vision characteristic. It is known that colors located on the same confusion loci on the xy chromaticity diagram are difficult to distinguish for Duteranope. Therefore, it is possible to estimate color combinations that are difficult for colorblind people to discriminate by examining colors that belong to the same confusion loci.

III. Mathod

A. Color Correction Intensity Map(CCImap)

We estimate the regions in the input images where the colorblind person has difficulty in discriminating colors compared to the normal person. The estimation is done using a* and b* components in $L^*a^*b^*$ color space. The geometric distance in the a^*b^* chromaticity diagram is proportional to the difference in color as perceived by humans. Fig. 2 shows a^*b^* chromaticity diagram with the confusion loci of Duteranope. Colorblind people cannot perceive hue changes parallel to the confusion loci, but they can perceive changes perpendicular to the confusion loci as well as normal people. From Fig. 2, we assume that Duteranope cannot perceive the a^* change, but can perceive the b^* change with sensitivity close to that of normal subjects. Therefore, we estimate the saliency of the a^*, b^* components of the input image.

We reconstruct the Gaussian pyramid of a* and b* component images with eight levels, $(I_{a^*1}, ...I_{a^*8})$ and $(I_{b^*1}, ...I_{b^*8})$. We then resize these images to the same size as the original. This produces a set of images in which the a^*, b^*-component images are gradually blurred. For each group of images in I_{a^*}, I_{b^*}, we compute the sum of difference of Gaussian:

$$M_{a^*} = \sum_{k=1}^{7} |I_{a^*k} - I_{a^*k+1}| \tag{4}$$

$$M_{b^*} = \sum_{k=1}^{7} |I_{b^*k} - I_{b^*k+1}| \tag{5}$$

Equations (4) and (5) extract the difference between one image and the next from the first level of the pyramid, and repeats the operation of adding them together. This allows pixels that are different from their surroundings to stand out more prominently. This method is based on the method for producing saliency map by Itti et al[7]. Thus, M_{a^*}, M_{b^*} obtained for each of the I_{a^*}, I_{b^*} image groups is a grayscale image representing saliency in each hue component of the original image. From the assumption, the regions where a^* components are more prominent and b^* components are less prominent are the regions where the gap in color discrimination between normal and colorblind people is large. Therefore, the size of the gap

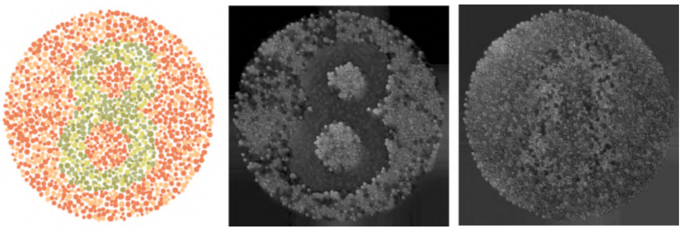

Fig. 3: Example of A^*, B^* component saliency
From left to right: original image, M_a^* image, M_b^* image

is used as an index of correction intency. The formula for determining the correction intency is as follows

$$I_{\text{CCImap}} = M_{a^*} + |M_{a^*} - M_{b^*}| \tag{6}$$

The M_{a^*} is used as the basis, and the regions where the change of M_{a^*} is strong with respect to M_{b^*} are emphasized. The two terms $M_{a^*}, |M_{a^*} - M_{b^*}|$ are pre-normalized so that the range of pixel values is 0-255 and then added together. The resulting image is used as Color Correction Intensity Map(CCImap).

B. Color Correction by Pix2pix

For color correction of images, we use pix2pix[8]. The training dataset is a pair of the original image and a degraded image. Degradation is done in such a way that it becomes difficult for Duteranope to distinguish colors. By having the model learn the inverse transformation from the degraded image to the original image, the model learns a color correction that makes color discrimination easier for Duteranope. From Fig. 2, the color perception of Duteranope strongly depends on the vertical direction, i.e., b^* component, of confusion loci. Therefore, the smaller the range of change in b^*, the more difficult it is for Duteranope to distinguish colors. Therefore, an image with a narrower range of b^* values in the $L^*a^*b^*$ color space is created for the input image, and is used as the degraded image. If all b^* values in the input image were fixed to 0, the hue of the image would be almost imperceptible to Duteranope, and the image would be similar to a grayscale image.

When performing model-based color correction, we adjust the range and intensity of the correction with reference to CCImap. This avoids unnecessary color changes, preserves saliency, and keeps the image natural for normal people. Normalize CCImap pixel values to continuous values between 0 and 1. Using this value, CCImap performs alpha blending between the original image and the pix2pix color-corrected image. Pixels with a CCImap pixel value of 0 are corrected to be the same as the original image, and pixels with a CCImap pixel value of 1 are corrected perfectly to the model. Thus, the output image is as follows

$$I_{\text{out}} = (1 - I_{\text{CCSmap}})I_{\text{orignal}} + I_{\text{CCSmap}}I_{\text{pix2pix}} \tag{7}$$

IV. Results and Discussion

500 pairs of color and degraded images were used to train the model. The degraded image is created in $L^*a^*b^*$ color space by reducing the b^* range of the original image from $-127 \leq b^* \leq 127$ to $-50 \leq b^* \leq 50$. Learning was performed with batch size=64, epoch=400, learning rate = 0.0002. The results are evaluated by creating color blindness simulated image from the original image and the output image and comparing them.

Some example is shown in Fig. 4. In the first image, the " 1 " in the color blindness simulation image is difficult to distinguish. In the second image, the bear is assimilated into the background color. The CCImaps have larger values in the regions of colors that are indistinguishable for the colorblind. The corrected images retain their natural hue compared to the original images, and normal people do not feel much discrepancy in the corrected images. From the corrected color blindness simulation images, we can see that the " 1 " and the bears can be distinguished from the background colors more easily than in the original images. The results show that CCImap and pix2pix can be used to perform color correction for colorblind people in a natural way when viewed by normal people.

In addition, we also experimented with gamma correction of CCImap and compared the output images by changing the gamma value. The results are shown in Fig. 5. The CCImap is becoming more bright and dark as the gamma value is increased. Comparison of the color blindness simulation images shows that as the gamma value is increased, the central bear and the background are more easily distinguished. Comparing the original images, the higher the gamma value, the more bluish the bear in the center becomes, resulting in unnatural tints. From these results, it is considered that the gamma correction to CCImap and increasing the gamma value will improve the ease of color discrimination for Duteranope. However, a large gamma value may degrade the naturalness of the image, so it is necessary to estimate the appropriate gamma value for each input image for the future work.

By applying this method to existing posters and websites, we can expect applications such as changing them to take color blindness into consideration without compromising the design. One of the problems is that there is a limitation in improving the ease of color discrimination for the colorblind compared to the method of re-coloring without regard to the hue of the original image. It is also necessary to develop a quantitative evaluation method of the results and to conduct a questionnaire survey of colorblind people.

V. Conclusions

In this paper, we examined a method using image processing to solve the inconvenience in daily life caused by color combinations that are difficult to distinguish for people with color blindness. We have therefore estimated the regions in which colorblind people have more difficulty in color discrimination than normal people in images based on confusion loci theory. We also proposed a method for creating images that are easy to see for people with color blindness while maintaining the hue and saliency of the original image by combining it with color correction based on learning pix2pix models. The result

Fig. 4: Color Correction Result

From left to right: original image, our method image, original image (simulation of Duteranope vision), our method image (simulation of Duteranope vision), CCImap

is a color correction for the colorblind while maintaining a more natural appearance.

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$\gamma = 1.0$ $\gamma = 2.0$ $\gamma = 3.0$ $\gamma = 4.0$

Fig. 5: Example of applying gamma correction to CCImap

From the top row, CCImap, our method image, our method image (simulation of Duteranope vision)