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IMAGE COLOR TRANSFORMATION FOR COLORBLIND USING MULTILAYER NEURAL NETWORK CONSIDERING DISCRIMINATION OF COLOR BOUNDARY

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Abstract. *In this paper, we propose an algorithm of learning based image color transformation for colorblind considering discrimination of color boundary using a multilayer neural network. The symptoms of colorblind are due to an innate lack or deficit of cone cells that recognize colors, and people with colorblind have difficulty discriminating combinations of specific colors. Those people require color transformation for the presented image such that the image can be a perceptible color representation. In the proposed method, we design a multilayer neural network composed of three blocks: layers for image color transformation, layers for perceptual model of colorblind, and layers for color discrimination. In the proposed framework, a neural network learns a relationship of image data and a discrimination performance of colors in an image, and a color transformation rule is trained as a part of a neural network. To verify its effectiveness of the proposed method, we apply the method to the images having various colors.*
Keywords: Color transformation, Neural network, Colorblind

1. **Introduction.** Human eyes have cells called cones that sense the light and recognize and differentiate colors. There are three types of cones, corresponding to red wavelength band, green wavelength band, and the blue wavelength band. Human can perceive color according to the strength of these responses. However, some people have defected eyes in color perception by the congenital or acquired reason.

On the other hand, color representation in modern society has been used in various fields as a means of information transmission. However, those of color representation are not necessarily easy to recognize for colorblind people. For example, a route map of the railway is composed of several colors to distinguish different lines. At that time, some colorblind people cannot discriminate other lines.

M. Ichikawa et al. [1] and M. Meguro et al. [2] proposed the color conversion methods based on color clustering. In these methods, the color conversion rule is determined based on a relationship of centroids of color obtained by clustering. However, there are some procedures to be performed by hand, and the procedures in these algorithms are complicated when many colors are in an image.

N. Suetake et al. [3] and G. Tanaka et al. [4] proposed the color conversion using contrast of colors. Indeed the method can keep the impression of color of original image; however, the method cannot improve the problem that colorblind people are difficult to distinguish colors compared with other methods.

In this paper, we propose a learning based image color transformation algorithm for colorblind considering color boundaries discrimination. This system is a multilayer neural network with three blocks. The 1st block performs color transformation of the image. The 2nd block corresponds to a perceptual model of the colorblind. The 3rd block corresponds to a color discrimination method. In the proposed method, compared with conventional [1,2], it is expected that there is no procedure to be performed by hand, and ever if many colors are in an image, the procedures in the algorithm are simple. And compared with conventional [3,4], the proposed method can perform image color transformation such that colorblind people can distinguish the color more easily. In the proposed framework as a color discrimination method is involved in a unified network, it is expected that color differences between pixels are preserved.

The remainder of this paper is structured as follows. The detailed procedures of the proposed method are introduced in Section 2. Specifically, Section 2.1 shows algorithm of the proposed method, Section 2.2 describes a neural network used in the proposed method, Section 2.3 presents a color model for colorblindness, and Section 2.4 presents a discrimination model of color boundary. Section 3 presents experimental results. Section 4 concludes this paper.

2. Proposed Method.

2.1. **Algorithm of the proposed method.** The structure of neural network employed in our proposed method is shown in Figure 1.

As shown in Figure 1, a multilayer perception involving 3 blocks is employed. Each block has a different function respectively. In the MLP, outputs of the 1st block are used as inputs of the 2nd block and outputs of the 2nd block and 3rd block, and simulate color perception of colorblinds, and color discriminately of an image, respectively. 2nd block and 3rd block in the MLP are designed in advance, and the weights of those blocks are fixed during learning of the whole neural network. The 1st block works as an image converter for colorblinds to make them perceive the image more clearly. The input of the MLP is RGB intensities of a small image patch. The teaching data of the MLP is central RGB intensities of the corresponding small image patch and ideal edge evolved by color combinations in the small image patch.

2.2. **Neural network.** Neural network is a mathematical model simulating human brain computation. In this study, an MLP is used as a unified framework to convert an image. In the following, details of neural computation are described.

A unit in layers except for the input layer is calculated as follows:

$$S_i = f\left(\sum_{j=1}^{n} W_{i,j} u_j + b_i\right) \tag{1}$$

where b_i is a bias team of unit i, and $W_{i,j}$ is a weight between unit i and unit j. u_j is an input of unit i conveyed from unit j. $f(x)$ is a transfer function, and S_i is output of a unit i.

In this study, sigmoidal function is used as a transfer function.

Moreover, these computations can be represented by Matrix notation, as follows:

$$S_i = f\left(\begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1N} \\ w_{21} & w_{22} & \cdots & w_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ w_{M1} & w_{M2} & \cdots & w_{MN} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_N \end{bmatrix}\right) \tag{2}$$

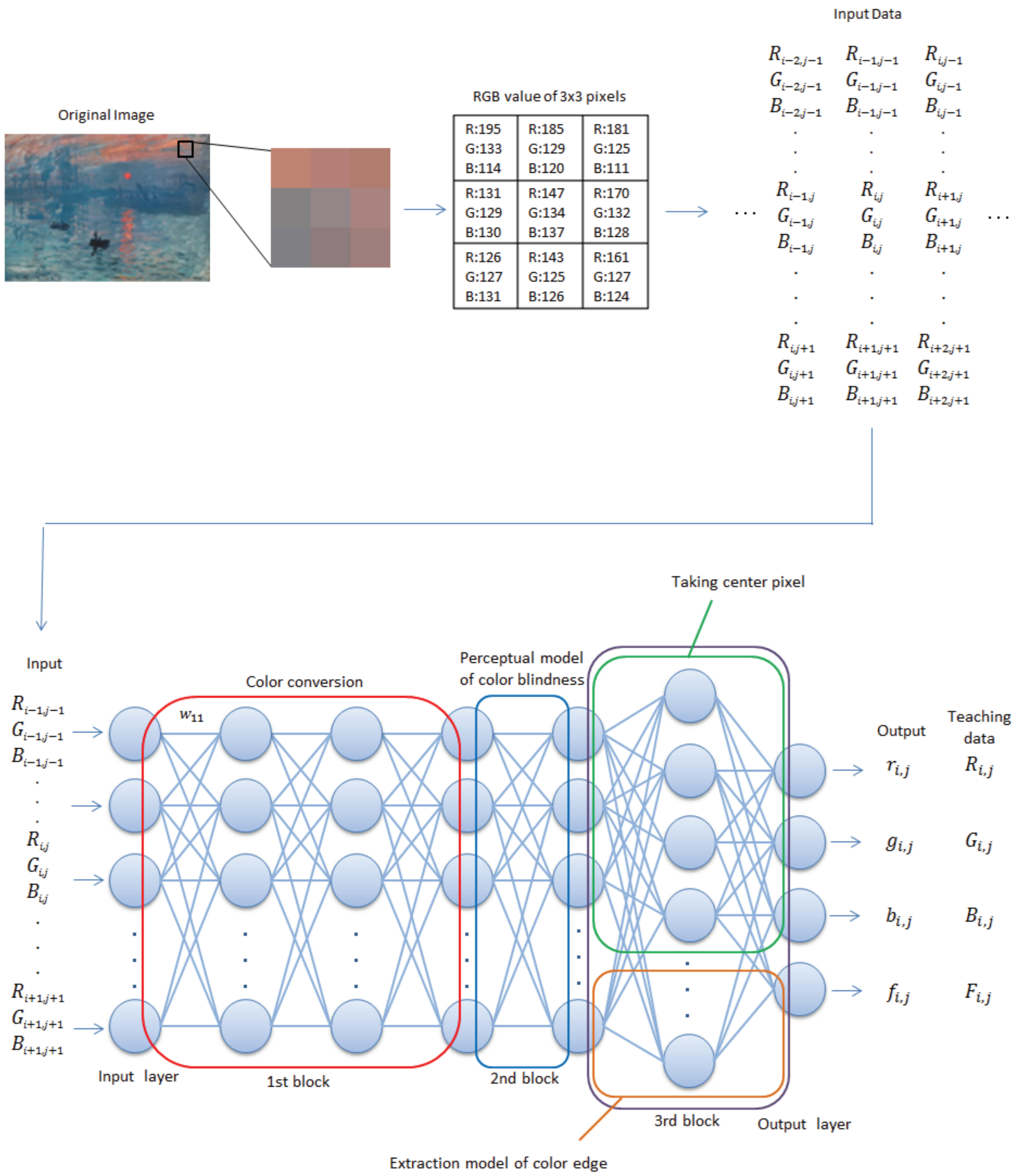

FIGURE 1. Overview of our multilayer neural network framework

2.3. **Color model for colorblindness (2nd block).** In the 2nd block, it performs a process that represents a color model for colorblindness in a neural network. In the proposed method, in order to perform image transformation for processing images on a computer colorblind person, it is necessary to model perform process of mathematically modeling the color of the colorblind people and converting the color of color blindness color image on a computer. Usually, when reading an image on a computer, the image read are converted to RGB values for each pixel. RGB values obtained from a normal image, i.e., the RGB values of the general color vision, use the following equation to convert into P-type color vision of the RGB values. $[R_p, G_p, B_p]$ shows the RGB values of the color model, P-type color vision.

$$\begin{bmatrix} R_p \\ G_p \\ B_p \end{bmatrix} = f\left(\begin{bmatrix} 0.2745 & 0.6750 & -0.0087 \\ 0.2948 & 0.7258 & 0.0035 \\ -0.0222 & 0.0207 & 0.9997 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}\right) \quad (3)$$

As described above, the color of the colorblind people can be represented by the matrix calculation. Because the calculation of the output of the neural network is carried out by a matrix operation of the input value, weight value and bias, using the above equations, it is possible to simulate the color of colorblind people by the neural network.

It shows Equation (4) as follows.

$$W = \begin{bmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \end{bmatrix} = \begin{bmatrix} 0.2745 & 0.6750 & -0.0087 \\ 0.2948 & 0.7258 & 0.0035 \\ -0.0222 & 0.0207 & 0.9997 \end{bmatrix} \tag{4}$$

To simulate color in the neural network, weighting matrix W, it may use the following values as a bias b.

$$W = \begin{bmatrix} w_{11} & w_{12} & w_{13} & 0 & 0 & 0 & \cdots & 0 \\ w_{21} & w_{22} & w_{23} & 0 & 0 & 0 & \cdots & 0 \\ w_{31} & w_{32} & w_{33} & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & w_{11} & w_{12} & w_{13} & \cdots & 0 \\ 0 & 0 & 0 & w_{21} & w_{22} & w_{23} & \cdots & 0 \\ 0 & 0 & 0 & w_{31} & w_{32} & w_{33} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & w_{33} \end{bmatrix} \tag{5}$$

$$b = [0] \tag{6}$$

The weighting matrix is the square matrix of $3 \times 3 \times 3$ of the input image. The transfer function is a linear function $f(x) = x$. Bias b is 0 matrix.

Thus, from this block, the value which is a pixel value subject to P-type color vision into an output of the 1st block $[Rp_{i-1,j-1}, Gp_{i-1,j-1}, Bp_{i-1,j-1}, \ldots, Rp_{i,j}, Gp_{i,j}, Bp_{i,j}, \ldots, Rp_{i+1,j+1}, Gp_{i+1,j+1}, Bp_{i+1,j+1}]$ is output $(3 \times 3 \times 3)$.

2.4. **Discrimination of color boundary (3rd block).** In the 3rd block, two different tasks are performed: extracting color edge by a Laplacian filter and taking a center pixel of 2nd block output. Therefore, the output of 3rd block is set as a vector $[r_{i,j}, g_{i,j}, b_{i,j}, pf_{i,j}]$, where $[r_{i,j}, g_{i,j}, b_{i,j}]$ is RGB intensities at the center pixel, and $pf_{i,j}$ is an output of Laplacian filtering. To this end, the former weight matrix W^{f1} and former bias b^{f1} should be set as below:

$$W^{f1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 1 \\ 0 & 0 & 0 & -1 & 0 & 0 & \cdots & 4 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & \cdots & 0 & 4 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & \cdots & 0 & 0 & 4 & \cdots & 0 \end{bmatrix}, \tag{7}$$

$$b^{f1} = [0], \tag{8}$$

where the dimension of the weight matrix W^{f1} is $(3 \times 3 \times 3 + 3) \times (3 \times 3 \times 3)$. The transfer function is set to be a linear function $f(x) = x$.

To average values obtained from each color plane and forward the center pixel values, the latter weight matrix W^{f2} and the latter bias b^{f2} should be set as follows:

$$W^{f2} = \begin{bmatrix} 0 & 0 & \cdots & 1 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & \cdots & 0 & 1 & 0 & \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 & 1 & \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 & 0.333 & 0.333 & 0.333 \end{bmatrix}, \tag{9}$$

$$b^{f2} = [0], \tag{10}$$

where the dimension of the weight matrix W^{f2} is $4 \times (3 \times 3 \times 3 + 3)$. The transfer function is set to be a linear function $f(x) = x$.

3. **Experimental Results.** In this section, we apply the proposed method to the images having various colors, to verify its effectiveness.

Figure 2 shows experimental results of our color transformation method. In this experiment, the images of Figure 2(a) are used as training images for our multilayer neural network in advance, Figure 2(c) are images applying previous method [4] for colorblind, and Figure 2(e) are obtained as the output vectors of the 1st block of our learnt neural

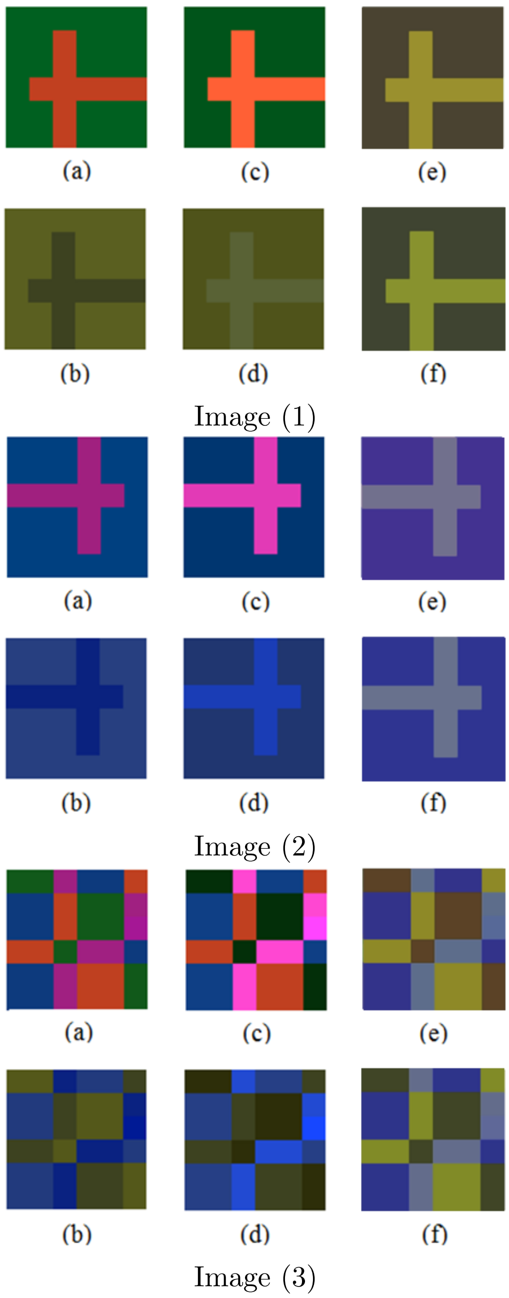

Figure 2. Experimental results of Images (1)-(3). (a) Input images, (b) simulated protanopia color vision of (a), (c) color transformation images by previous method, (d) protanopia color vision of (c), (e) color transformation images by proposed method, and (f) protanopia color vision of (e).

Table 1. Color difference of Figures 2(1) and 2(2)

	Original image (a)	Original image looked colorblind (b)	Image applied previous method looked colorblind (d)	Image applied proposed method looked colorblind (f)
Image (1)	91.3	5.4	10.0	49.6
Image (2)	54.2	9.7	38.8	49.1

network. And we show that Table 1 shows color difference between the color of the cross section and otherwise section in Figures 2(1) and 2(2).

In Table 1, color transformation for colorblind on the original image shows small value of color difference. Compared to that, color transformation on the image that applied the proposed method shows larger value than it. And compared with previous method, the proposed method shows larger value than it, so we are easy to distinguish color on the image.

4. **Conclusions.** We proposed learning based image color transformation algorithm for colorblind considering color boundaries discrimination. In the proposed method, we design a multilayer neural network with three blocks: layers for image color transformation, layers for perceptual simulation of colors of the colorblind, and layers for color discrimination. The 2nd block and the 3rd block are predesigned based on perceptual model of colorblind and color discrimination, and these models are fixed while the neural network is learning overall, and a color transformation rule for colorblindness is trained as a part of a neural network (1st Block). In the experiment, we applied some of the images to this technique and compared the results to confirm the validity of the proposed method.

If color conversion processing speed is quicker, the proposed method will be possible to apply to video conversion on real time. Also, in this paper, we used a perceptual model of the colorblind to perform color transformation, but if we replace the model to others, the method will be able to apply to other color image processings.

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