Letter

Evaluation of the Artificial Neural Network for Color Discrimination – Discrimination of Non-learned Colors –

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ABSTRACT

Our research purpose is to build an artificial neural network with an excellent color discrimination capability like human being on a computer. In this study, we built the network, which was trained to learn 10 colors with different hues in the Munsell color system. Then, we examined the response of the trained network when the network was interrogated about 10 non-learned colors. The network showed a good color discrimination capability, close to that of human being.

KEYWORDS : color discrimination, artificial neural network, spectral reflectance distribution, Munsell color system

1. Introduction

In the color test of industrial products, the human's excellent color discrimination capability is often required. But human's color vision has some problems, such as individual differences and weariness. So, we aim to realize an artificial neural network with an excellent color discrimination capability like human being on a computer. Such an artificial neural network would also give a hint for us to understand the mechanism of human's sense of color. In this study, we built the network, which relates the spectral reflectance distribution to one of three attributes, that is, hue in the Mussel color order system. After training the network to learn 10 colors with different hues, we examined the color discrimination capability for 10 non-learned colors.

2. Structure and study data of the network

Figure 1 shows the sense-of-color model to build the artificial neural network with a color discrimination capability. Figure 2 shows the three-layered network based on the model in Fig. 1. In the input layer, the normalized spectral reflectance distribution $I(\lambda)$ of object color, calculated by eq. (1), is treated as the input data.

$$I(\lambda) = (R(\lambda) - R_{min}) / (R_{max} - R_{min}) \quad (1)$$

Where $R(\lambda)$ is the standard spectral reflectance distribution of object color[1]. Also, R_{max} is the maximum value of $R(\lambda)$, and R_{min} the minimum one. In this study, $I(\lambda)$'s at the wavelengths of 400, 450, 500, 550, 600, 650 and 700nm were put into the input layer of the network. Therefore, the input layer consists of seven units, corresponding to each wavelength.

In the hidden layer, a number of units was set to be 5. The output layer provides the result of the color perception, which is expressed with hue in Munsel color system[2]. There are five principal hues: red (R), yellow (Y), green (G), blue (B), and purple (P), which are placed at equal intervals around circle. The hue circle is arbitrarily divided into 100 steps of equal visual change in hue. So, any hue is identified by a distance, or a step difference, from the principal hues. Therefore, we assign five units, corresponding to the distance Ii from

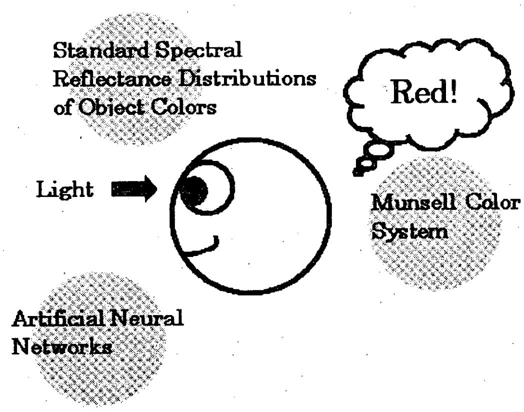

Figure 1 The sense-of-color model

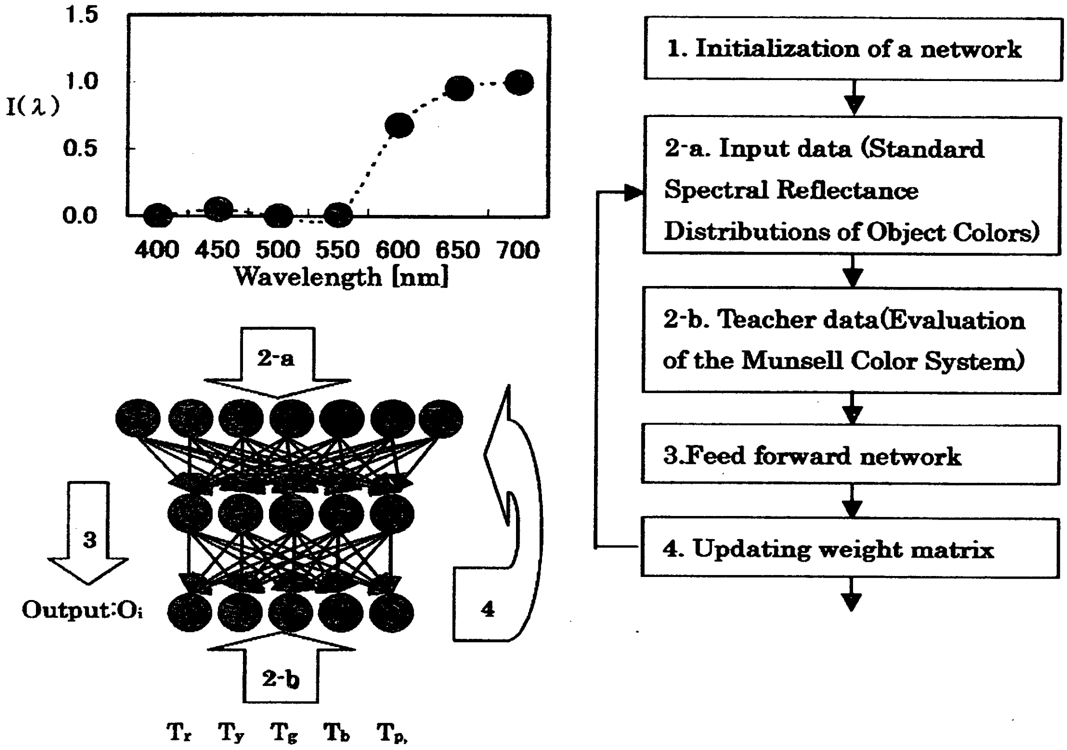

Figure 2 Structure of the network

the principal hues, to the output layer. The output value T_i of each unit is related with the distance l_i as follows:

$$
\begin{aligned}
T_r &= 0.9 - 0.04 \times l_r \\
T_y &= 0.9 - 0.04 \times l_y \\
T_g &= 0.9 - 0.04 \times l_g \quad \cdots\cdots (2) \\
T_b &= 0.9 - 0.04 \times l_b \\
T_p &= 0.9 - 0.04 \times l_p \\
& (0 < l_i < 20)
\end{aligned}
$$

For any colors, the output values T_i's are determined by distances between hue of the color and the principal hues, and are limited from 0.1 to 0.9 to train the network rapidly and stably. In training the network, we used the conventional back-propagation algorithm[3]. As the training set, 10 colors, i.e. the principal hues and the intermediate ones, i.e. YR, GY, BG, PB and RP, with a value of 6 and a chroma of 8 were used. The desired outputs for 10 colors were calculated from eq. (2).

Table 1 The square of error for 10 non-learned colors

	Er	Ey	Eg	Eb	Ep
2.5 R	0.0077	0.0001	0.0001	0.0000	0.0080
7.5 R	0.0060	0.0016	0.0005	0.0000	0.0000
2.5 YR	0.0061	0.0002	0.0004	0.0000	0.0000
2.5 Y	0.0092	0.0033	0.0010	0.0000	0.0000
2.5 GY	0.0000	0.0014	0.0012	0.0000	0.0000
7.5 G	0.0009	0.0000	0.0055	0.0008	0.0000
10 G	0.0014	0.0000	0.0101	0.0023	0.0004
2.5 BG	0.0002	0.0000	0.0000	0.0000	0.0003
2.5 B	0.0000	0.0000	0.0090	0.0077	0.0000
7.5 P	0.0063	0.0000	0.0000	0.0000	0.0054

3. Results

In the neural network, the learning process was repeated 100,000 times for each color of the training set. Then, we put into the data of 10 non-learned colors to examine the color discrimination capability of the trained network. The discrimination capability was evaluated by the square of error E_i, which is a difference between the actual output O_i and the desired output T_i.

$$E_i = T_i - O_i \quad \cdots\cdots (3)$$

It is said that human cannot discriminate two colors when a hue difference between them is less than one step. In the network, a hue difference of 1 corresponds to a difference of 0.04 in the output unit. Therefore, if the squares of errors for all units in the output layer were less than $(0.04)^2$, the color discrimination capability would be superior to that of human being.

Moreover, the network was evaluated by *MSE* (Mean Square Error). If a number of the color data is *N*, *MSE* is defined by

$$MSE = \frac{1}{N} \cdot \left(\sum_{N} \sum_{i} E_i^2 \right) \quad (4)$$

Since MSE converged in an order of 10^{-4} for 10 colors of the training set, the learning process was successfully finished.

The square of error for each non-learned color is shown in Table 1. For the non-learned colors of 2.5GY and 2.5BG, since the square of error is less than $(0.04)^2$, the two colors can be precisely discriminated by the network. In addition, the maximum square of error $E^2{}_{(max)}$ is found to be 0.0092 from the Table 1. Using the maximum value, the discriminating hue difference ΔH of the network is given by

$$\Delta H = \sqrt{E^2{}_{(max)}} / 0.04 \quad (5)$$

The discriminating hue difference ΔH is evaluated to be 2.4. Therefore, the network is slightly inferior to human being with a discriminating hue difference ΔH of 1. It is, however, surprising that such a simple network showed a good color discrimination capability, close to that of human being. Incidentally, *MSE* is 0.0098 for 10 non-learned colors. Since the value of *MSE* is close to that for 10 learned colors, the network would be generalized enough to adapt to the non-learned colors.

4. Conclusion

We built the three-layered artificial neural network based on the human's sense-of-color model. Its discriminating hue difference ΔH was evaluated to be 2.4, close to that of human being. The color discrimination capability could be further improved by increasing a number of colors of the training set in the supervised learning and by optimizing the network configuration. Regarding the network configuration, the normalized spectral reflectances for seven wavelengths were used as the input values. The number of wavelengths was not be optimized, so that it has yet to be examined. Also, We are starting to examine the artificial neural network based on the stage theory, which receives a support as the mechanism of the sense of color in human being from many researchers.

References

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