Primary Consideration Related to Chromatic Adaptation from a New Viewpoint

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Abstract

From a new viewpoint, primary consideration related to chromatic adaptation is performed. In the long history of study on chromatic adaptation, almost all models have been constructed based on psychometric testing. In this paper, the hypothetical principle of chromatic adaptation is defined as the minimization of the state of the metameric black component of an image, which enhances the efficiency of visual perception. There have been no discussions related to chromatic adaptation from the viewpoint of metameric black control.

1. Introduction

Chromatic adaptation is the most important characteristic among the characteristics related to human vision. Since von Kris developed a chromatic adaptation model, many researchers have conducted research on chromatic adaptation; various models based on results of psychometric testing have been constructed.[1] In this study, referencing the previous studies, the principle of processing of visual information is investigated, and the hypothetical principle of chromatic adaptation is as follows: the chromatically adapted state is the minimized state of the metameric black component, i.e., the ineffective component of an obtained image, and the minimized state has the effect of enhancing the efficiency of perception.

Chromatic adaptation has been considered as an adaptation to white point, but there exists a contradiction here. Namely, even if the obtained image does not include white points, chromatic adaptation occurs. In other words, it is considered that adaptation to white points is not the basic mechanism of chromatic adaptation, and that chromatic adaptation is carried out on the basis of some rational controls. The maximum color separation (MCS) model[2] was published on the basis of this viewpoint. This model was developed on the basis of a mathematical characteristic in which the centroid of the color gamut corresponds to an ideal white point when the color gamut is maximized by adjusting the sensitivity of three color channels. This model explains the phenomenon of chromatic adaptation occurring even when the obtained image does not include white points, using the framework of three stimulus values. MCS is based on a concept of maximizing the processing efficiency of visual information, which corresponds to the maximization of the color gamut, i.e., the maximization of color separation. There is a similarity between the concept explained above and the idea discussed in this paper, i.e., the minimization of information loss in the spectral region.

In this paper, the discussions will be extended to spectral region, which will be recognized indirectly in our visual system. Although the number of color channels is three, it is meaningful to consider information loss during the propagation of spectral information in our visual system. There have been no discussions related to chromatic adaptation from the viewpoint of the control of the metameric black component.

2. Metameric Black

Spectral power distributions $s_{MB}(\lambda_i)$ are considered to be metameric black, when the corresponding three stimulus values satisfy the following relation.

$$X = \sum_{i=1}^{n} s_{MB}(\lambda_i)\bar{x}(\lambda_i)\Delta\lambda = 0,$$

$$Y = \sum_{i=1}^{n} s_{MB}(\lambda_i)\bar{y}(\lambda_i)\Delta\lambda = 0, \quad (1)$$

$$Z = \sum_{i=1}^{n} s_{MB}(\lambda_i)\bar{z}(\lambda_i)\Delta\lambda = 0.$$

where

i : index of discrete sampling wavelength,
$\bar{x}(\lambda_i), \bar{y}(\lambda_i), \bar{z}(\lambda_i)$:color-matching functions,
n : number of samples.

3. Principle Hypothesis

In this paper, I propose the hypothetical principle with which chromatic adaptation minimizes the state of the metameric black component, i.e., the ineffective component of an obtained image, and has the effect of enhancing the efficiency of perception. Here, minimization of the state of the metameric black component corresponds to minimization in the framework of the R-matrix developed by Cohen.[3]

4. Minimized State of Metameric Black Component and Chromatic Adaptation

According to Cohen's R-matrix, the spectrum, G, is separated into fundamental and metameric black components. In this arithmetic logic, the state of the metameric black component is nonexplicitly minimized in terms of the minimization of the square value explained below. It is known that the metameric black component is expressed in the form of $G(\lambda_i)-\{k_x\bar{x}(\lambda_i)+k_y\bar{y}(\lambda_i)+k_z\bar{z}(\lambda_z)\}$ for each wavelength, λ_i, according to Cohen's R-matrix. By arithmetic logic, Eq. (2) is minimized so that the distance between a point in the space containing the metameric black component and another point in the fundamental space, which is expressed by linear coupling of the color-matching function, is minimized.[3]

$$SS=\sum_{i=1}^{n}\left[G(\lambda_i)-\{k_x\bar{x}(\lambda_i)+k_y\bar{y}(\lambda_i)+k_z\bar{z}(\lambda_z)\}^2\right] = \sum_{i=1}^{n}\{s_{MB}(\lambda_i)\}^2 \quad (2)$$

The local minimum providing the minimum SS value is determined using,

$$\frac{\partial SS}{\partial k_x}=-\sum_{i=1}^{n}2s_{MB}(\lambda_i)\bar{x}(\lambda_i)=0,$$
$$\frac{\partial SS}{\partial k_y}=-\sum_{i=1}^{n}2s_{MB}(\lambda_i)\bar{y}(\lambda_i)=0, \quad (3)$$
$$\frac{\partial SS}{\partial k_z}=-\sum_{i=1}^{n}2s_{MB}(\lambda_i)\bar{z}(\lambda_i)=0.$$

According to Eq. (3), k_x, k_y and k_z which correspond to the minimum SS values, are obtained using simultaneous equations.

In the framework explained above, as a result of chromatic adaptation performed to minimize the state of the metameric black component, G is considered to be equivalently changed into G'. G' is a function that depends on the color-matching function or other parameters, and contains linear and nonlinear frameworks.

$$SS=\sum_{i=1}^{n}\left[G'(\lambda_i,G(\lambda_i),\alpha_x\bar{x}(\lambda_i),\alpha_y\bar{y}(\lambda_i),\alpha_z\bar{z}(\lambda_i),\alpha_1;\cdots,\alpha_k) -\left(u_x(\alpha_x\bar{x}(\lambda_i))+u_y(\alpha_y\bar{y}(\lambda_i))+u_z(\alpha_z\bar{z}(\lambda_i))\right)\right]^2 =\sum_{i=1}^{n}\{s_{MB}(\lambda_i)\}^2 \quad (4)$$

where

$\alpha_x,\alpha_y,\alpha_z,\alpha_1;\cdots,\alpha_k$: parameters related to chromatic adaptation,

$u_x\alpha_x=k_x$,
$u_y\alpha_y=k_y$,
$u_z\alpha_z=k_z$,
G' : spectrum obtained equivalently as a result of chromatic adaptation.

k_x,k_y and k_z are obtained when

$$G'(\lambda_i,G(\lambda_i),\alpha_x\bar{x}(\lambda_i),\alpha_y\bar{y}(\lambda_i),\alpha_z\bar{z}(\lambda_i),\alpha_1;\cdots,\alpha_k)$$

is given. Since u_x, u_y, and u_z can be set independent of α_x, α_y, and α_z which are related to chromatic adaptation, once G' is determined, $k_x=\alpha_x u_1$, $k_y=\alpha_y u_2$, and $k_z=\alpha_z u_3$ can be obtained as a function of G' alone.

5. Discussion

Discussion 1: Squared Summation

The squared sum of the state of the metameric black components has meaning associated with energy, whose validity becomes an issue. Assuming that the framework of Cohen's R-matrix is valid, the minimized local minimum of the square sum is considered to be valid.

Discussion 2: Calculation of Metameric Black Component

The metameric black components after chromatic adaptation are expressed by $G'(\lambda_i)-\{k_x\bar{x}(\lambda_i)+k_y\bar{y}(\lambda_i)+k_z\bar{z}(\lambda_z)\}$. G' is a function of $\bar{x}$, $\bar{y}$ and $\bar{z}$, and when G' is determined, the state of the metameric black component should be determined as a function of G' alone. Assuming that k_x, k_y and k_z are dependent on a_x, a_y and a_z, metameric black components should be determined depending on $\bar{x}$, $\bar{y}$ and $\bar{z}$, after the determination of G'; this contradicts the fact that the metameric black component is determined as a function of G' alone. As explained above, k_x, k_y and k_z are determined independent of a_x, a_y and a_z. This concept does not include any contradiction, indicating the validity of the calculation of the metameric black component.

Discussion 3: Discussion on Preliminary Experiment and Results

It is considered that chromatic adaptation is achieved by the adjustment of the sensitivities of the three color matching functions. As a result of such adjustment, the spectrum, G, is equivalently deformed and G' is obtained. This deformation is expressed using a function including linear and nonlinear frameworks. The entity of the function will be discussed in a future article. In this paper, as a preliminary experiment, a numerical experiment is carried out to examine the conditions of G' (equivalently obtained as a result of chromatic adaptation), under which the state of metameric black components is minimized. First, to simplify the discussion, the case in which light from a light source is completely reflected is considered. As G' after chromatic adaptation, ten kinds of spectra, having the chromatic coordinates shown in Table 1 were used in the experiment. In the table, state values of the metameric black components minimized at each G' (normalized using Y value) are also shown.

As Table 1 indicates, G' corresponding to minimization has chromatic coordinates in the vicinity of $D65$. The results of chromatic adaptation correspond to whitening of the light source. In other words, minimization of the state of the metameric black component, i.e., the ineffective component, leads to normalization or whitening of the light source. If the nature of chromatic adaptation is considered to be the normalization of the light source as a result of optimizing the processing of information related to human vision, i.e., minimizing ineffective information, rather than the adaptation to white point, the validity of our viewpoint is demonstrated.

Table 1. Squared Sum of Metameric Black (MB) Components

(x,y)	MB	(x,y)	MB
(0.477, 0.427)	0.231	(0.418, 0.411)	0.126
(0.358, 0.343)	0.090	(0.326, 0.340)	0.045
(0.346, 0.352)	0.062	(0.393, 0.398)	0.096
(0.366, 0.361)	0.085	(0.316, 0.334)	0.038
(0.347, 0.351)	0.063	(0.317, 0.320)	0.046

6. Conclusion

In this paper, from the viewpoint of examining the principle of the processing of visual information, a hypothetical principle of chromatic adaptation was defined as follows: the chromatically adapted state is the minimized state of the metameric black component, i.e., the ineffective component, of an obtained image, and has the effect of enhancing the efficiency of perception. By examining the minimization of the state of metameric black components, I obtained preliminary results that the minimization of the state of metameric black components corresponds to normalization, i.e., whitening of the spectrum of a light source. The validity of this viewpoint is demonstrated by considering that a light source is normalized as a result of optimizing the processing of visual information, i.e., minimizing ineffective information.

In this article of the preliminary experiment, the case in which light from a light source is completely reflected was considered. The discussion on the spectral reflectance of a real object under general conditions will be reported in another article.

References

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