Consideration on Crispening Phenomenon based on Maximum Color Separation Model

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Abstract

Crispening is the phenomenon whereby the color differences between two stimuli are perceptually larger when viewed on a background that is similar to the stimuli. The phenomenon is discussed and simulated based on a color constancy model called Maximum Color Separation (MCS). The simulation results have shown the same results with the generally known results related to the crispening phenomenon.

Introduction

As well known, crispening is the phenomenon whereby the color differences between two stimuli are perceptually larger when viewed on a background that is similar to the stimuli.[1] In this paper, the phenomenon is discussed based on a color constancy model called Maximum Color Separation (MCS).[2,3] Based on the model, the relationship between the phenomenon and the contribution of adjusting the sensitivity of the color matching functions is discussed.

In the application of MCS to the analysis of the phenomenon, the robust background of MCS is included. Using MCS, numerical experiments of the crispening phenomenon have been performed. Sample color patches were generated by computer simulations, and each data was analyzed by a MCS computer program. The results have shown the same results with the generally known results related to the crispening phenomenon.

Outline of MCS

Human visual system has an ability called chromatic adaptation or color constancy to remove the influence of illuminants. The von Kries model is predominantly employed for formulating the chromatic adaptation or color constancy. The model is based on the assumption that white always remains white for any illuminant adjusting the sensitivity of respective receptors without changing the basic shape of spectral sensitivities. However the chromatic adaptation or color constancy occurs even though there are no whites in a viewing field. Based on this phenomenon, we have tried to establish a new model different from the von Kries model. We can generally notice that under white illuminants, object colors look more vivid than under colored illuminants. This phenomenon has long been noticed, but it has never been applied directly in the research of chromatic adaptation and color constancy. This phenomenon has been employed to MCS. In MCS, the assumption is that the chromaticity gamut of an image reaches its maximum (maximum color separation) under white illuminant based on the phenomenon. As in the von Kries model, we assume that color can be transformed to the one under any other arbitrary illuminant through the diagonal transform. We further assume that our visual system adapts in such a way that the separation of respective colors is maximized thus giving the maximum chromaticity gamut. Related to MCS it has been proven that when representing the chromaticity gamut with a general convex polygon, the centroid of the maximized chromaticity gamut coincides with $(1/3,\ 1/3)$ of the ideal white. The white point centroid implies the most balanced vivid color reproduction noticed visually in general under white illuminants. It is estimated that the balancing mechanism will contribute to various phenomena of the human visual system. The discussion with the robust theoretical background has clear discrimination from the existing experimental discussions.

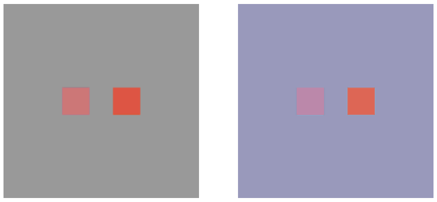
The mathematical description of MCS is included in Appendix.

Numerical Illustrations Using MCS

Using MCS, numerical experiments of the crispening phenomenon were performed. Sample color patches were generated by computer simulations, and each data was analyzed by a MCS computer program.

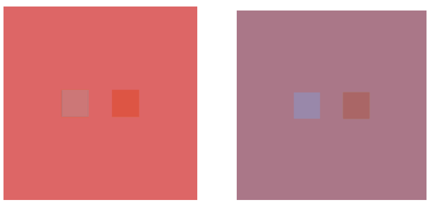
A background color and two color stimuli composed each color patch in Figures I-1(a) and I-2(a). In this case, the chromaticity gamut is constructed by three colors and the gamut region becomes to a triangle. The parameters η_R, η_G, η_B were optimized using the non-linear simplex method.

Tables I-1 and I-2 are results for Figures I-1(a) and I-2(a), respectively. Background color and two color stimuli for the original color patch are shown, and crispening phenomenon was predicted using MCS as shown in the tables. The results of the MCS prediction in Tables I-1 and I-2 are illustrated in Figures I-1(b) and I-2(b), respectively.



(a) (b)

Figure I-1



(a) (b)

Figure I-2

Table I-1

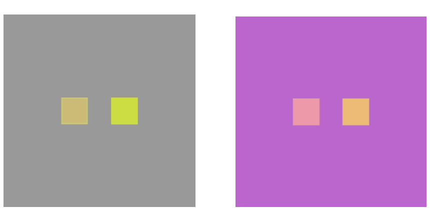
	Background (R, G, B)	Two Stimuli (R, G, B)
Original	(151, 145, 147)	(192, 122, 124) (218, 92, 69)
MCS prediction	(145, 158, 190)	(185, 135, 162) (210, 107, 95)

Table I-2

	Background (R, G, B)	Two Stimuli (R, G, B)
Original	(217, 101, 96)	(192, 122, 124) (218, 92, 69)
MCS prediction	(163, 112, 129)	(143, 127, 164) (164, 100, 91)

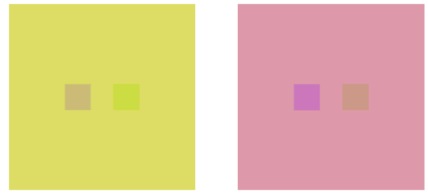
The crispening phenomenon in the MCS prediction has been confirmed in the chromaticity diagram.

Other than I, the same results have been derived for II, III, IV and V following.



(a) (b)

Figure II-1



(a) (b)

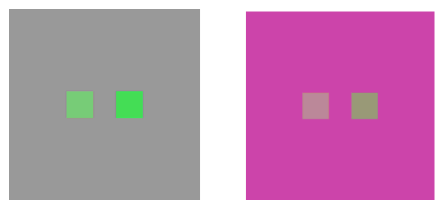
Figure II-2

Table II-1

	Background (R, G, B)	Two Stimuli (R, G, B)
Original	(151, 145, 147)	(193, 191, 123) (196, 219, 67)
MCS prediction	(178, 110, 194)	(225, 154, 172) (230, 182, 122)

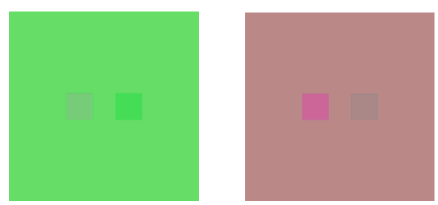
Table II-2

	Background (R, G, B)	Two Stimuli (R, G, B)
Original	(212, 218, 96)	(193, 191, 123) (196, 219, 67)
MCS prediction	(209, 146, 161)	(191, 123, 183) (196, 150, 131)



(a) (b)

Figure III-1



(a) (b)

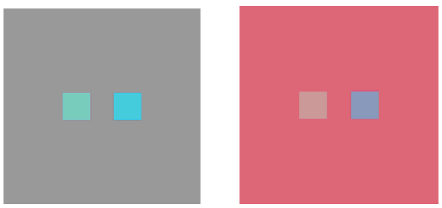
Figure III-2

Table III-1

	Background (R, G, B)	Two Stimuli (R, G, B)
Original	(151, 145, 147)	(125, 193, 123) (67, 219, 92)
MCS prediction	(199, 79, 163)	(184, 128, 144) (148, 153, 119)

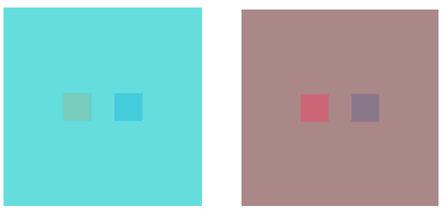
Table III-2

	Background (R, G, B)	Two Stimuli (R, G, B)
Original	(96, 218, 101)	(125, 193, 123) (67, 219, 92)
MCS prediction	(181, 131, 143)	(197, 107, 160) (159, 136, 128)



(a) **(b)**

Figure IV-1



(a) **(b)**

Figure IV-2

Table IV-1

	Background (R, G, B)	Two Stimuli (R, G, B)
Original	(151, 145, 147)	(123, 193, 191) (67, 196, 219)
MCS prediction	(216, 99, 119)	(194, 147, 156) (138, 154, 179)

Table IV-2

	Background (R, G, B)	Two Stimuli (R, G, B)
Original	(96, 212, 218)	(123, 193, 191) (67, 196, 219)
MCS prediction	(175, 128, 141)	(195, 110, 123) (139, 122, 143)

Considerations

The results in this paper have shown the same results with the generally known results related to the crispening phenomenon.

The existing researches have been based on experimental results of the crispening phenomenon. On the other hand, this research is based on the theoretical assumption related to the human visual system which is a new approach to the phenomenon. Though the crispening phenomenon is a complex visual phenomenon processed by the visual system and the brain system, the discussions in this paper using MCS describes one of estimation related to the mechanism of the phenomenon though a first-ordered approximation model.

Conclusions

The existing researches have been based on experimental results of the crispening phenomenon. On the other hand, this research is based on the theoretical assumption related to the human visual system which is a new approach to the phenomenon.

Hereafter, the results will be compared with such as ICAM which is one of the representative image appearance model.

References

1)M. D. Fairchild, Color Appearance Models, Second Edition, John Wiley & Sons.

2)N. Matsushiro and N. Ohta, Japan Patent Application Publication Pub. No. JP2004-157901 A, Application date Nov. 8 2002.

3)N. Matsushiro and N. Ohta, United States Patent Application Publication Pub. No. US2004/0091147 A1, Foreign Application Priority Date Nov. 8 2002.

Appendix

: Mathematical Description of MCS

The color space used is the (r, g) color space in which the following transform is performed from (R, G, B) color space.

$$r = \frac{R}{R+G+B},$$

$$g = \frac{G}{R+G+B}, \qquad (A.1)$$

$$b = \frac{B}{R+G+B}.$$

The transform framework from one illuminant to another illuminant to give new (R', G', B') is assumed to be a diagonal transform as follows:

$$R' = \eta_R \cdot R,$$

$$G' = \eta_G \cdot G, \qquad (A.2)$$

$$B' = \eta_B \cdot B,$$

where, η_R , η_G and η_B are transform coefficients, and applied to the three channels of R, G, B , respectively. The chromaticity coordinates transformed by Eq.(A.2) are calculated using Eq.(A.1), and are denoted by (r', g', b'). When the chromaticity gamut area S becomes the maximum by varying η_R , η_G and η_B , we should obtain

$$\frac{\partial S}{\partial \eta_R} = \frac{\partial S}{\partial \eta_G} = \frac{\partial S}{\partial \eta_B} = 0 . \quad \text{(A.3)}$$

By solving Eq.(A.3), the coefficients of η_R, η_G and η_B to give the maximum chromaticity gamut can be obtained.

The aspect to be considered is the relation between the phenomenon assumption and the property with the parameter values of η_R, η_G and η_B derived from Eq.(A.3). The area of the polygon transformed through the diagonal transform is calculated by using the following equation.

$$S = \frac{1}{2}\left(\begin{vmatrix} r_1' & g_1' \\ r_2' & g_2' \end{vmatrix} + \begin{vmatrix} r_2' & g_2' \\ r_3' & g_3' \end{vmatrix} + \cdots + \begin{vmatrix} r_n' & g_n' \\ r_1' & g_1' \end{vmatrix} \right). \quad \text{(A.4)}$$

A series of transform leads the numerators of $\partial S / \partial \eta_R$, $\partial S / \partial \eta_G$ as follows respectively and should be zero.

$$\sum_{i=1}^{n} \left(1 - r_i' - r_{i+1}'\right)\left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right) = 0., \quad \text{(A.5)}$$

$$\sum_{i=1}^{n} \left(1 - g_i' - g_{i+1}'\right)\left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right) = 0.$$

Eq.(A.5) are in the most simplest form with some transforms. Through some transforms, the following simple formulas are derived.

$$\sum_{i=1}^{n} \left(r_i' + r_{i+1}'\right)\left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right) = \sum_{i=1}^{n} \left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right), \quad \text{(A.6)}$$

$$\sum_{i=1}^{n} \left(g_i' + g_{i+1}'\right)\left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right) = \sum_{i=1}^{n} \left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right).$$

From the expansion of Eq.(A.4), the right side of Equation (A.6) is twice the area of chromaticity gamut polygon. Then Equation (A.6) can be transformed as follows:

$$\sum_{i=1}^{n} \left(r_i' + r_{i+1}'\right)\left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right) = 2 \cdot S , \quad \text{(A.7)}$$

$$\sum_{i=1}^{n} \left(g_i' + g_{i+1}'\right)\left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right) = 2 \cdot S .$$

On the other hand, the coordinates of the centroid of convex polygons are calculated by using the following equations.

$$r'_{centroid} = \frac{1}{6} \frac{\sum_{i=1}^{n} \left(r_i' + r_{i+1}'\right)\left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right)}{S} , \quad \text{(A.8)}$$

$$g'_{centroid} = \frac{1}{6} \frac{\sum_{i=1}^{n} \left(g_i' + g_{i+1}'\right)\left(r_i' \cdot g_{i+1}' - r_{i+1}' \cdot g_i'\right)}{S} .$$

By applying Eq.(A.7) to Eq.(A.8), the coordinates of the centroid coincide with $(1/3, 1/3)$. That is,

$$r'_{centroid} = 1/3 , \quad \text{(A.9)}$$

$$g'_{centroid} = 1/3 .$$

The result indicates that when representing the chromaticity gamut with a general convex polygon, the centroid of the maximized chromaticity gamut coincides with $(1/3,\ 1/3)$ of the ideal white. The white point centroid implies the most balanced vivid color reproduction noticed visually in general under white illuminants. The result of Eq.(A.9) is the robust theoretical background of MCS.

It is estimated that the balancing mechanism will contribute to various phenomena of the human visual system.

Biography

Nobuhito Matsushiro received his PhD degree (Information engineering) from University of Electro. Communications, Tokyo, Japan, in 1996 and PhD degree (Color science) from Chiba University in 2006. He is a PhD (MD) candidate at School of Medicine, Chiba University, Chiba, Japan. He works for Oki Electric. Co. Ltd., Printing Company Oki Data.