

Neutral Point Model Adapted for the Variations of the Luminance

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Abstract:

In this paper, we propose the Luminance-Adapted Neutral Point Model, LANPM, for the variations of the luminance levels under the same illuminant. LANPM is modeled by the transform between the other luminance levels. In the model, the optimal coefficients are obtained from the Hunt's experimental result. The gain coefficient of the conventional chromatic adaptation model is taken to be the L, M and S cone responses for the scene white stimulus. However it is applied in the chromatic adaptation model using gain coefficients for the neutral point of the various viewing conditions. And the LANPM can be used as the theoretical standard which determines the reference white of the color display devices.

Key words : neutral point, human visual system, corresponding colors

1. Introduction

For the purpose of color reproduction under standard viewing conditions, recently, color display devices have developed for the colorimetric and the preferred color reproduction [1]. However the real viewing condition of color display devices is quite different from that. If the HVS is adapted chromatically under a variety of viewing situations, the same chromaticities will appear as quite different colors. Therefore, it is very important for reproduced colors viewed under real conditions to match the color appearance under standard situations.

There are various models that can be used to reproduce corresponding colors considering the chromatic adaptation according to the change of surround illuminants' chromaticity under the same luminance conditions [2]-[7]. However, there is almost unknown the quantitative analysis for the chromatic adaptation for the variations of the luminance levels under the same illuminant. And only the human visual characteristic for the variations of the luminance levels has been studied [4]-[5],[8]-[9]. And the chromatic adaptation models considering such phenomenon have scarcely been proposed.

In this paper, we propose the LANPM for the various luminance levels with Hunt's experimental result. The quantitative model for the various luminance levels can

be used to reproduce corresponding colors considering human visual system (HVS).

2. Previous experiment and model for various luminance levels

Chromatic adaptation to reflect the HVS about the variations of the luminance levels has hardly been modeled and neutral point is always the same. Breneman [5] had experimented on corresponding color for different state of adaptation. While each of his or her two eyes were independently adapted to a different luminance level in viewing field, each of observers matched a series of test colors seen by one eye with a various stimulus seen by the other eye.

CAM ΔY was modeled according to the change of luminance level under the same illuminants [11]. It was derived from the corresponding colors data of the Breneman's experiments. The forecast ability of the CAM ΔY is good. But it isn't the proper model to detect the neutral point for various luminance and illuminants owing to the insufficient experiment data.

Hunt [9] had experimented on the neutral point for diverse adapting fields. Observers were adapted to each adapting field for five minute, then being shown the range of sample. The adapting field subtended an angle of about 30° at the observer's eye. Neutral points were determined for each of the eleven adaptation condition.

3. Proposed neutral point model to be adapted for the variation of the luminance

The luminance level under the sunlight is about 10000 cd/m² and the luminance level of the living room is about 10 cd/m² in average [10]. Thus the reproduced colors in the real viewing conditions for watching the color display devices will appear to be different due to the variation of the luminance level. HVS is adapted chromatically under viewing conditions in the different luminance levels of illuminants. Accordingly, the reproduced colors having the same chromaticity will appear as quite different color. Therefore it is important to detect a neutral point for the luminance

change. We propose the quantitative model for the variation of the luminance level.

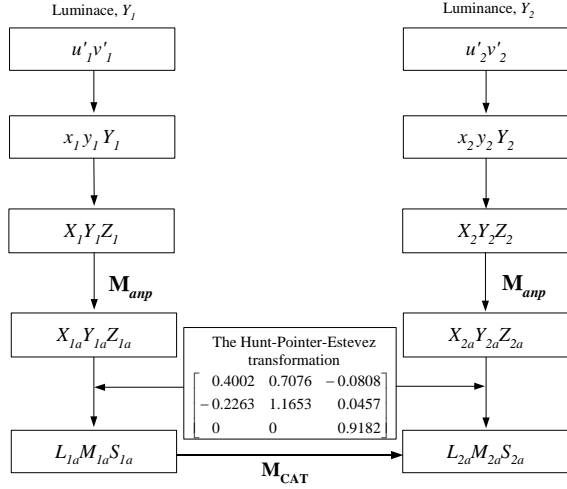


Fig. 1: A block diagram for the chromatic adaptation using the proposed LANPM

In Fig. 1, the proposed model is obtained by transform the CIE tristimulus values XYZ to $X_a Y_a Z_a$ considering human visual characteristic.

$$\begin{bmatrix} X_a \\ Y_a \\ Z_a \end{bmatrix} = \mathbf{M}_{amp} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [\mathbf{M}_{ij}]_{3 \times 3} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (1)$$

$$[\mathbf{M}_{ij}]_{3 \times 3} = \begin{bmatrix} M_{11} & M_{12} & 0 \\ 0 & M_{22} & 0 \\ M_{31} & M_{32} & M_{33} \end{bmatrix} \quad (2)$$

$$M_{ij} = a_{ij} + b_{ij}(\log(Y_r)) + c_{ij}(\log(Y_r))^2 + d_{ij}(\log(Y_r))^3 \quad (3)$$

Where, Y_r represents the luminance ratio, Y_2/Y_1 . Y_1 and Y_2 are maximum white luminance under a certain surround viewing conditions, $Y_2 > Y_1$, Y_2 is 10000 cd/m², the luminance level of white under the sunlight. And M_{amp} represents 3×3 transfer matrix for chromatic adaptation according to the variations of the luminance levels under the same illuminants and also the element, M_{ij} of transfer matrix is modeled by maximum luminance ratio, in Eq. (3). The remaining elements of transfer matrix are 0, because of a negligible quantity.

In the proposed model, the optimal coefficients of each element in transfer matrix are obtained from the neutral point data of the Hunt's experiments [9]. And these optimal coefficients and element functions are shown in Table I, Fig. 2 and Fig. 3, respectively. Y_r is

log-scale. M_{11} , M_{22} , and M_{33} assume the similar form for Y_r . M_{12} , M_{31} , and M_{32} are the factor of the fine adjustment.

Once the surround viewing condition is determined, the proposed model has the coefficient of linear transformation and can be easily applied to the color display devices.

Table I: Element functions' coefficients of the transfer matrix of the proposed LANPM.

M_{ij}	a_{ij}	b_{ij}	c_{ij}	d_{ij}
M_{11}	0.236127	-0.238463	0.079615	-0.008769
M_{12}	-0.01446	0.022991	-0.009535	0.0011919
M_{22}	0.22182	-0.215768	0.070227	-0.007598
M_{31}	0.0096571	-0.019651	0.0085579	-0.0010708
M_{32}	-0.027298	0.048127	-0.020417	0.0025542
M_{33}	0.238429	-0.242869	0.081576	-0.0090233

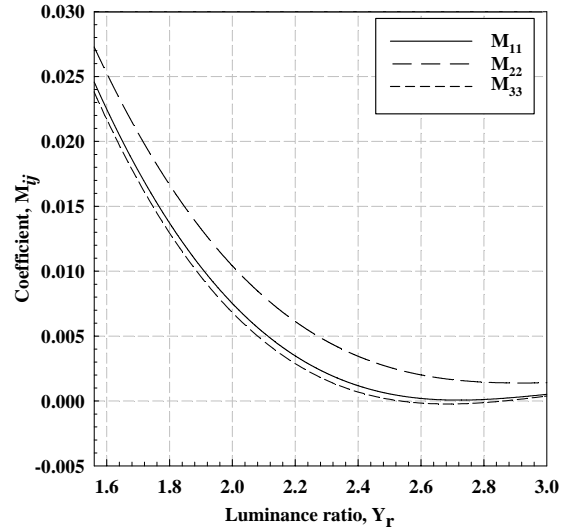


Fig. 2: Element functions of the proposed transfer matrix : M_{11} , M_{22} , and M_{33}

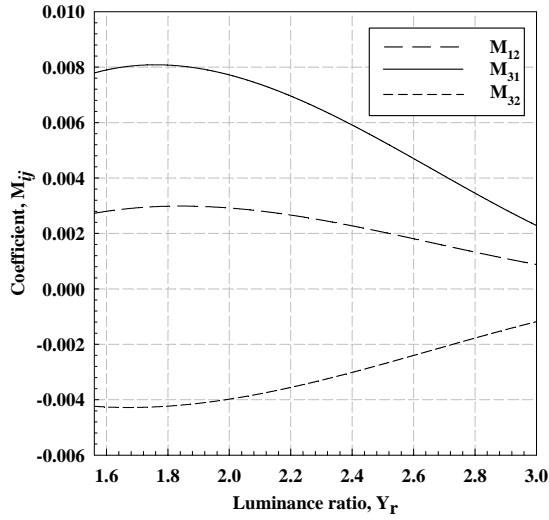


Fig. 3: Element functions of the proposed transfer matrix: M_{12} , M_{31} , and M_{32}

4. Results and Discussions

The performance of LANPM is evaluated in term of the chromaticity and color reproduction error. Table II shows chromaticity errors, $\Delta u'v'$ and color reproduction errors, ΔE_{uv}^* between the predicted neutral point by LANPM and neutral point by the adaptation condition. This result is based on the data of Hunt's experiment. In the experimental results, we confirmed that the chromaticity errors between the predicted points by LANPM and the neutral points of the Hunt's experiments fall within 0.004 in a $u'v'$ chromaticity coordinates. It is known that two adjacent color patches can usually be distinguished with a $\Delta u'v'$ over 0.004, but for separated colors, a shift $\Delta u'v'$ over 0.04 is often required for human eyes to notice a color change in the $u'v'$ chromaticity coordinates system [1].

Therefore, the prediction performance of LANPM is excellent because $\Delta u'v'$ has less value than the threshold value by which two adjacent color patches can be distinguished.

And Chromatic adaptation models provide the prediction of corresponding colors and can be used to predict required reproduction colors for changes in viewing conditions. There are various models to reproduce corresponding colors considering the chromatic adaptation of HVS under various viewing conditions. The gain coefficients of models are taken to be the L, M and S cone responses for the white stimulus on the scene. However we confirm that the chromatic adaptation using adaptive neutral point can

predict corresponding colors better than conventional chromatic adaptation models. By implementing a corresponding color reproduction system that apply to LANPM, the reproduction colors viewed in the real viewing conditions could appear as the original object colors under standard situations. Table III shows chromaticity errors among the conventional chromatic adaptation models. von Kries model is the most simple corresponding color reproduction model but has the lost performance of the prediction. As LANPM is applied in von Kries model, we can see that the difference of $\Delta u'v'$ has about 15% smaller. As LANPM is applied in other models, we can expect higher efficiency of the prediction.

We can also obtain the same CCT curves using LANPM according to the luminance levels of the surround viewing conditions. We estimate variation of samples of Hunt's experiments using the proposed model, LANPM. Fig. 4 shows the same whiteness curve for various CCT and luminance. Y_r is the ratio of Y_1 and Y_2 , Y_2/Y_1 . Y_2 is luminance 10000 cd/m^2 . The reason we set luminance 10000 cd/m^2 is to obtain CCT equally with a white of sunlight. As Y_r has the large value, CCT of the neutral point lies between about 5500 and 6000K. As shown in Fig. 4, the analyzed CCT curves for various CCT and luminance levels can be used as the theoretical standard which determines the reference white of the color display devices.

Table II: Chromaticity errors and reproduction errors of the proposed LANPM

	Luminance of the adapting field			
	35 cd/m^2		70 cd/m^2	
	$\Delta u'v'$	(ΔE_{uv}^*)	$\Delta u'v'$	(ΔE_{uv}^*)
Eleven adaptation condition				
2985 K	0.006238	7.752563	0.003472	4.498403
3350 K	0.004635	5.864901	0.000361	0.475709
4000 K	0.002863	3.84661	0.003458	4.48029
4500 K	0.001609	2.555613	0.000799	1.038349
4975 K	0.001273	2.25843	0.00169	2.190496
5500 K	0.002361	3.306467	0.002108	2.73205
5900 K	0.001063	2.09213	0.000725	0.943521
6650 K	0.00374	4.831457	0.002366	3.066051
6900 K	0.004363	5.54871	0.002948	3.8195
9800 K	0.003749	4.84097	0.001418	1.839166
17240 K	0.006281	7.803464	0.002893	3.748596
Average	0.003471	4.60921	0.002021	2.621103

Table III: Chromaticity errors between conventional chromatic adaptation models and chromatic adaptation using LANPM

Illuminant	Luminance [cd/m ²]	Chromaticity error, $\Delta u'v'$				
		von Kries	von Kries using LANPM	Breneman	Fairchild	Bartleson
A-D65	15	0.0429	0.0465	0.0369	0.0240	0.0211
	75	0.0308	0.0187	0.0262	0.0167	0.0176
	350	0.0293	0.0196	0.0255	0.0152	0.0184
	1500	0.0195	0.0219	0.0169	0.0174	0.0215
A-D55	11100	0.0104	0.0104	0.0104	0.0219	0.0220
Average		0.02658	0.02342	0.02318	0.01904	0.0212

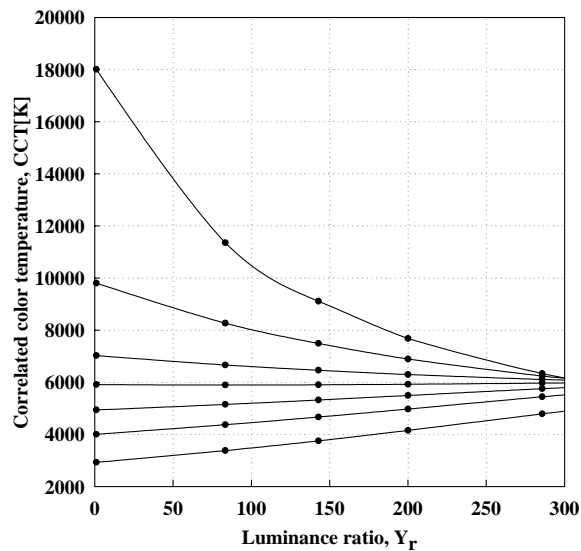


Fig. 4: The same whiteness curved by the proposed LANPM

5. Conclusion

In this paper, we propose the adaptive neutral point model, LANPM, for the variations of the luminance levels under the same illuminants. LANPM is obtained by the transfer matrix between the different luminance levels. In LANPM, the optimal coefficients are obtained from the neutral point data of the Hunt's experiments. And once the surround viewing condition is determined, LANPM has the coefficient of linear transformation and can be easily applied to the color display devices.

In the experimental results, we confirmed that the chromaticity errors between the predicted point by LANPM and the neutral point of the Hunt's experiments fall within 0.004 in $u'v'$ chromaticity coordinates. The prediction performance of LANPM is excellent because it has the smaller error than the

threshold value that two adjacent color patches can be distinguished. Additionally, we can also obtain same CCT curves by LANPM according to the luminance levels of the surround viewing conditions. And these curves can be used as the theoretical standard which determines the reference white of the color display devices.

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