Establishment of Display White Point Considering Adaptative Neutral Point for the Various Viewing Conditions

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Abstract: *In typical display viewing conditions, observers are perceptible as different color temperatures at the luminance levels, illuminant, and reference white of display. In the same luminance level, adaptive neutral point(NP) of human visual system(HVS) is determined by not only illuminant's correlated color temperature(CCT) but also display reference white. However, if luminance level is not as high as sun light, HVS's chromatic adaptation is incomplete. In this paper, we predict the adaptive NP for the various display's CCT under a diversity of illuminant. We discuss the NP of illuminant and display when incompletely adapted, and investigate adaptive NP of HVS in typical display viewing condition*

Key words: neutral point, incomplete adaptation

1. Introduction

Several color appearance models have been proposed and some of the models produce very accurate predictions of color appearance. However, since they tried to predict color appearance for the complete range of viewing conditions, these models need a significant number of viewing condition parameters, and are somewhat too complex to implement[9]. They are assumed that observers have a fixed state of single adaptation[1][2]. However, soft-copy images viewed under illuminant have not yet been evaluated. Chromatic adaptation is of great importance when considering color reproductions viewed by ambient light and by self luminance display[8]. These two systems are often operated at very different color temperatures. So, Chromatic adaptation to mixed illuminants occurs[8]. In such a case, human visual system is partially adapted to the CRT monitor's white point and partially to the ambient light. Research on a soft copy image vs. a hard copy image matching indicated that the human visual system is 60% adapted to the CRT monitors white point and 40% to the ambient light when seeing a soft copy image[9], but adaptation to the picture area was found to be incomplete, except for CCT in the range 5500K to 6500K[8]. If CCT of display's white point and ambient light were not found in the range 5500K to 6500K, HVS is not completely adapted to the display's white point and the ambient light. In viewing display under illuminant, observers adapt to different color temperatures neither display's, nor ambient light's CCT. We need to find adaptive NP of HVS, because CCT of display and illuminant are various.

2. von Kries Model

One of the early models of chromatic adaptation, von Kries model[11] was based on the idea that the three cone systems adjust their individual sensitivities linearly and independently:

$$L' = k_l L, \quad M' = k_m M, \quad S' = k_s S \qquad (1)$$

where LMS are the cone responses before they are adapted to one illuminant, L', M', S' are cone response after they are adapted to another illuminant, and k_l, k_m, k_s are three constants. The model is called the von Kries coefficient rule and the transformation from L, M, S to L', M', S' is called the von Kries transformation[11].

3. Incomplete adaptation experiment data

R. W. G. HUNT[8] investigated that adaptation to the picture area was found to be incomplete, except for color temperatures in the range 5500 to 6500K. The chromaticities that appeared neutral were determined for observers adapted to viewing conditions typical for projected transparencies. Neutrality was determined by a naming technique. The color naming technique used was found to be satisfactory for determining subjective neutral points for the conditions of adaptation studied. Adapting fields typical of those occurring when viewing projected slides only appeared nearly neutral when their color temperatures were between about 5500 and 6500K; at greater color temperatures they appeared bluer than neutral, and at lower color temperatures, yellower. Figure 1 shows chromaticities on u, v diagram for adapting fields at a lower level of adapting luminance(35 cd/m^2). The triangle symbols represent subjective neutrals for each adaptation field. Figure 2 shows chromaticities on u, v diagram for adapting fields at a high level of adapting luminance (70 cd/m^2)[8].

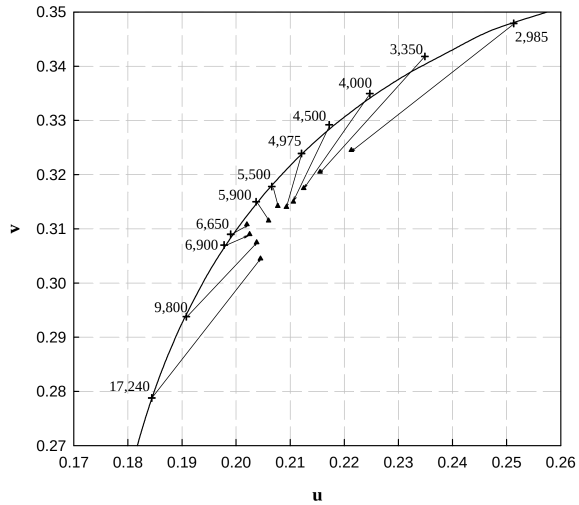

Fig. 1: Chromaticities on u, v diagram for adapting fields at 35 cd/m^2: adaptation fields: + ; subjective neutrals: ▲; Planckian locus shown thus: ____

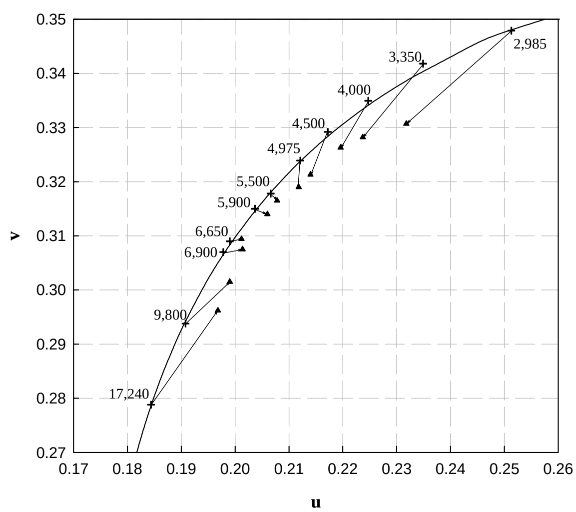

Fig. 2: Chromaticities on u, v diagram for adapting fields at 70 cd/m^2:adaptation fields: + ; subjective neutrals: ▲; Planckian locus shown thus: ____

Figure 3 show the CCT of NP at the level of adapting luminance(35 cd/m^2 , 70 cd/m^2). This shows that the differences from neutrality were less for a high level of adapting luminance(70cd/m^2) than for a lower level (35cd/m^2).

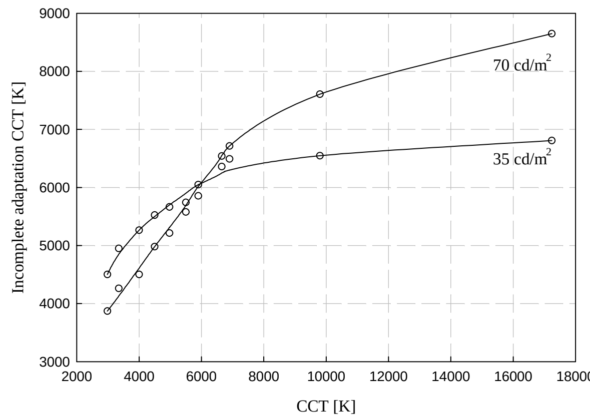

Fig. 3: Correlated color temperature of Fig.1 and Fig.2

4. Proposed method

In this paper, Adaptation modeling essentially consists of three stages: 1)transformation from CIE tristimulus values *XYZ* to the fundamental *LMS* cone signal, 2)compensation of incomplete adaptation, and 3)partial adaptation.

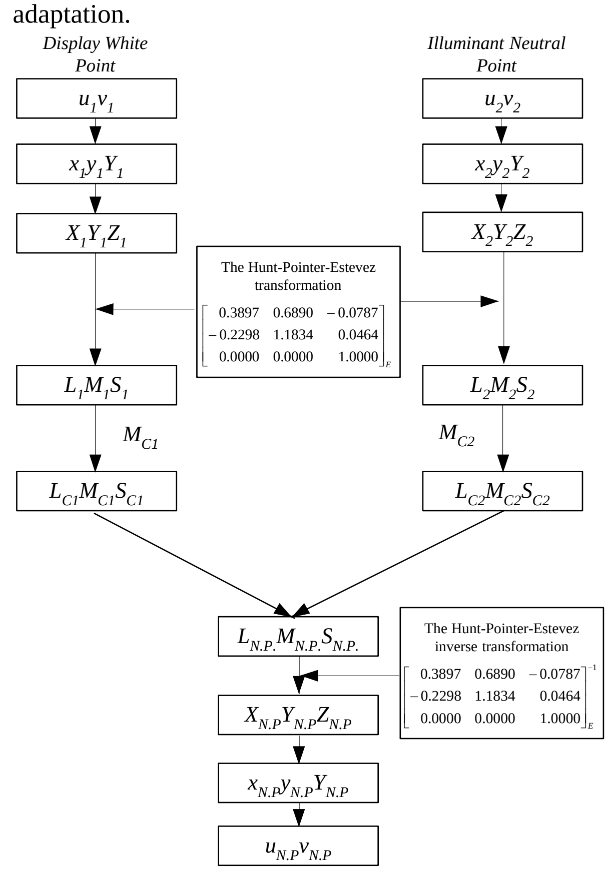

Fig. 4: Flow chart for the process of image transformation to set up a neutral point

4.1 Transformation from CIE tristimulus values XYZ to the fundamental LMS cone signal

The first step is a transformation from the CIE tristimulus values XYZ to the fundamental tristimulus LMS. The Hunt-Pointer-Estevez transformation[4] with illuminant(E) normalization is used, since it is desirable to normalize the cone signals for equality for the self-luminous colors[10]. This matrix is also used in hunt's color appearance model[10].

$$\begin{bmatrix} L_{(display)} \\ M_{(display)} \\ S_{(display)} \end{bmatrix} = \mathbf{M} \begin{bmatrix} X_{(display)} \\ Y_{(display)} \\ Z_{(display)} \end{bmatrix} \tag{2-1}$$

$$\mathbf{M} = \begin{bmatrix} 0.3897 & 0.6890 & -0.0787 \\ -0.2298 & 1.1834 & 0.0464 \\ 0 & 0 & 1.0000 \end{bmatrix}_E \tag{2-2}$$

The tristimulus values of display's white point must be transformed into cone signal beforehand for the next step, compensation of incomplete adaptation.

$$\begin{bmatrix} L_{n(display)} \\ M_{n(display)} \\ S_{n(display)} \end{bmatrix} = \mathbf{M} \begin{bmatrix} X_{n(display)} \\ Y_{n(display)} \\ Z_{n(display)} \end{bmatrix} \tag{3}$$

4.2 Compensation for incomplete adaptation

The second step in the adaptation point calculation is the compensation for the incomplete chromatic adaptation of the human visual system for the self-luminous displays[5]-[7]. Adaptation to the picture area was found to be incomplete, except for color temperatures in the range 5500 to 6500K[8]. Even if the display is placed in a totally dark room, the human visual system's chromatic adaptation to a display's white point will not be complete. If the CCT of display and illuminant were not found in the range 5500K to 6500K, HVS is not completely adapted to the display's white point and the illuminant,. Observer adapted to different color temperatures at display's white point, and ambient light. We need to determine NP to compensate incomplete chromatic adaptation. In Figure 1 and Figure 2, ▲ means subjective neutrals. With the NP for the display and illuminant, the von Kries model[11] is applied. Thus, the viewing-condition independent index: $S-LMS$ can be expressed as below.

In matrix form:

$$\begin{bmatrix} L_{NP(display)} \\ M_{NP(display)} \\ S_{NP(display)} \end{bmatrix} = \mathbf{M}_{C(display)} \begin{bmatrix} L_{(display)} \\ M_{(display)} \\ S_{(display)} \end{bmatrix} \tag{4-1}$$

$$\mathbf{M}_{C(display)} = \begin{bmatrix} k_{l(display)} & 0 & 0 \\ 0 & k_{m(display)} & 0 \\ 0 & 0 & k_{s(display)} \end{bmatrix} \tag{4-2}$$

$$k_{l(display)} = \frac{L_{n(display)}}{L_{N.P(display)}}$$

$$k_{s(display)} = \frac{S_{n(display)}}{S_{N.P(display)}} \tag{5}$$

$$k_{m(display)} = \frac{M_{n(display)}}{M_{N.P(display)}}$$

$L_{NP(display)}$, $M_{NP(display)}$, and $S_{NP(display)}$ are compensated $S-LMS$, NP of display. $\mathbf{M}_{C(display)}$ is the chromatic adaptation compensation matrix for the CCT of display. L_n, M_n, and S_n are $S-LMS$ for display' white point. Using the same method, we can determine NP for illuminant.

4.3 Partial adaptation

The third step, chromatic adaptation has not yet a fixed state of single adaptation[1][2], when considering color reproductions viewed by ambient light and by self luminance display. These two systems operate at very different color temperatures. In such a case, the HVS is partially adapted to the display white point and partially to the ambient light[9]. Therefore, the adapting NP for the HVS for softcopy images can be established as the inter-mediate point of these two systems' NP. A_{ratio} is the adaptation ratio to the display white point. When the A_{ratio} is equal to 1.0, the HVS is assumed to be totally adapted to the NP for the display white point. When the ratio is 0.0, the HVS is assumed to be quite adapted to the NP for the illuminant's white point[9]. Equations (7) represent $S-LMS$ of adapting NP considering white points of illuminant and display. These equations are assumed as a same luminance level.

$$\begin{bmatrix} L_{NP} \\ M_{NP} \\ S_{NP} \end{bmatrix} = A_{ratio} \begin{bmatrix} L_{NP(display)} \\ M_{NP(display)} \\ S_{NP(display)} \end{bmatrix} + (1-A_{ratio}) \begin{bmatrix} L_{NP(Illuminant)} \\ M_{NP(Illuminant)} \\ S_{NP(Illuminant)} \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} L_{NP} \\ M_{NP} \\ S_{NP} \end{bmatrix} = A_{ratio} \mathbf{M}_{C(display)} \begin{bmatrix} L_{(display)} \\ M_{(display)} \\ S_{(display)} \end{bmatrix} + (1-A_{ratio}) \mathbf{M}_{C(illuminant)} \begin{bmatrix} L_{(illuminant)} \\ M_{(illuminant)} \\ S_{(illuminant)} \end{bmatrix} \tag{7}$$

$S-LMS$ are transformed into $S-XYZ$ using the inverse of the Hunt-Pointer-Estevez transformation matrix normalized to illuminant E[10], and then to CIE LUV.

$$\begin{bmatrix} X_{NP} \\ Y_{NP} \\ Z_{NP} \end{bmatrix} = \mathbf{M}^{-1} \begin{bmatrix} L_{NP} \\ M_{NP} \\ S_{NP} \end{bmatrix} \quad (8\text{-}1)$$

$$\mathbf{M}^{-1} = \begin{bmatrix} 1.9102 & -1.1122 & 0.2019 \\ 0.3709 & 0.6291 & 0.0000 \\ 0.0000 & 0.0000 & 1.0000 \end{bmatrix}_E \quad (8\text{-}2)$$

$$L^*_{NP} = 116\left(\frac{Y}{Y_n}\right)^{1/3} - 16$$

$$u^*_{NP} = \frac{4X_{NP}}{X_{NP} + 15Y_{NP} + 3Z_{NP}} \quad (9)$$

$$v^*_{NP} = \frac{6Y_{NP}}{X_{NP} + 15Y_{NP} + 3Z_{NP}}$$

5. Prediction of neutral point

Proposed method produce prediction of human visual system's adapting NP considering white of illuminant and display. Figure 5 is prediction of adapting NP when the HVS is 60% adapted to the display white point and 40% to the ambient light at 35 cd/m^2, then the A_{ratio} is equal to 0.6. Figure 5 is prediction of adapting NP when the HVS is 60% adapted to the display white point and 40% to the ambient light at 70 cd/m^2, then the A_{ratio} is equal to 0.6.

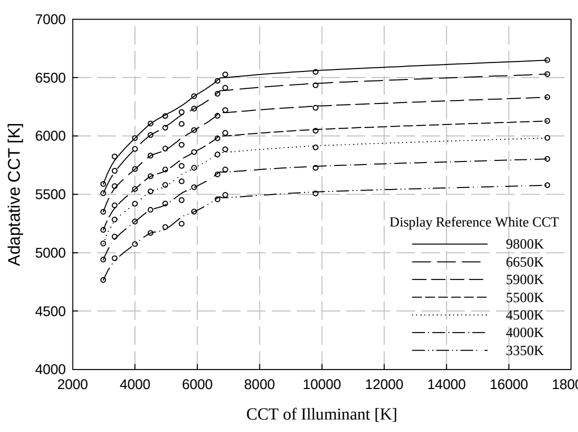

Fig. 5: CCT of neutral point considering display reference white and illuminant for adapting fields at 35 cd/m^2

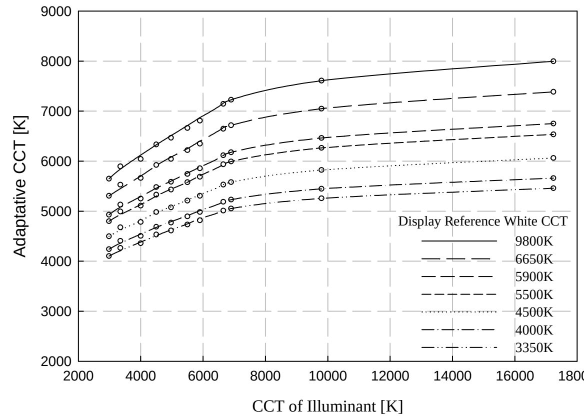

Fig. 6: CCT of neutral point considering display reference white and illuminant for adapting fields at 70 cd/m^2.

6. CONCLUSION

Proposed method produce the prediction of human visual system's adapting NP considering white point of illuminant and display. In typical indoor viewing condition, display is seen under illuminant. These conditions operate at very different color temperatures, and chromatic adaptation to the picture area was found to be incomplete, except for CCT in the range 5500K to 6500K[8] because luminance level is not as high as under sun light. Then, NP of HVS is found neither display white point nor illuminant. Therefore, the adapting NP for the HVS can be established as the inter-mediate point that is 60% adapted to the display neutral point and 40% to the illuminant neutral point, when seeing a soft copy image. When the reproduced color was viewed by variety of display under a diversity of viewing condition, by applying the proposed adaptive NP modes, we can improve the soft copy reproduction of conventional model.

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