

EFFECT OF AMBIENT LIGHT ON COLOR APPEARANCE OF SOFT COPY IMAGES ~ Color Management on the Network ~

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With the widespread of CMSs (color management systems), it is now guaranteed that users can achieve device independent color across different devices and media. However, current CMSs guarantee the same color only if one sees color under a certain controlled viewing condition. If one sees color under a different viewing condition, the reproduced color won't match the original. On the other hand, the network environment enables users to send color images from one place to another that has different viewing condition. In this case, it is impossible to achieve the same color appearance with current CMSs. In this paper, the effect of the ambient light on the color appearance of soft copy images is discussed. In a typical office environment, one uses a computer graphic monitor with a CCT (correlated color temperature) of 9300K in a room illuminated with white fluorescent light of 4150K CCT. In such a case, human visual system is partially adapted to the CRT monitor's white point and partially to the ambient light. Our previous research on soft copy image vs. hard copy image matching^{1,2} indicated that the human visual system is 60% adapted to the CRT monitor's white point and 40% to the ambient light when seeing a soft copy image. Here, visual experiments were performed for matching between soft copy images seen under different viewing conditions. Simultaneous haploscopic matching technique was applied to simulate a different viewing condition for each eye. The experimental results indicated that human visual system is 60% adapted to the monitor's white point and 40% to the ambient light as in our previous researches.

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. Furthermore, soft-copy images viewed under mixed chromatic adaptation have not yet been evaluated. It is assumed that observers have a fixed state of single adaptation^{3,4}. When one is designing an image on a CRT screen under a certain viewing condition, one's state of adaptation is affected by both the monitor's white point and the viewing condition that are different. Also, one is not only staring at the monitor all the time, but sees surrounding at intervals, thus one's adaptation is not fixed at single state.

The effect of ambient light on color appearance of CRT has been studied by several people. Brainard et al.⁵ and Choh et al.⁶ used an achromatic color matching method under a fixed state of adaptation. In Brainard's experiments, it was found that for a small test patch (1.35 x 1.35 deg.) adaptation shift from the monitor's white point caused by the ambient light was about 10-20% in CIE1931/xy coordinates. Choh used a test patch of 2 x 2 deg. and defined the adaptation shift ratio in CIE1976/u'v' coordinates. He has performed the experiments for three different types of illuminants and at three levels of ambient luminance. When the CRT was set to 9300K and the ambient illuminance was F2, the shift from the monitor's white point was about 15%. In both Brainard's and Choh's experiments, shift was subtle. Katoh^{1,2} and Berns et al.⁷ used pictorial images for cross-media color reproduction under mixed chromatic adaptation. In Katoh's experiment, soft-copy images on the CRT screen were compared with the hard-copy image under an F6 illuminant. It was found that the human visual system was 60% adapted to the monitor's white point and 40% to the ambient light, when seeing soft-copy images on a CRT screen (note that the adaptation shift from the monitor's white point is 40%). Berns et al. have also performed visual experiments for a soft-copy image viewed under a mixed state of chromatic adaptation compared with the hard copy image. Their results were similar to Katoh's previous experiment; an image with an adaptation shift of 50% was most preferred.

2. ADAPTATION MODELING

Adaptation modeling in this paper essentially consists of three stages: 1) compensation for contrast variation, 2) transformation from tristimulus values to cone signals, and 3) compensation for chromatic adaptation.

1) Contrast Compensation:

First, the contrast variation caused by the ambient light must be compensated. An important effect of ambient light is the variation of the perceived image contrast in accordance with the surround's luminance level. This contrast difference is mainly caused by the reflection of the ambient light on the CRT screen. The black on the CRT screen will not be dark enough because the reflection of the ambient light still exists, although most of the monitors have anti-glare filter on the surface of the CRT screen. Monitors have no means of producing black darker than this reflection. Since the human visual system is more sensitive to dark areas and less sensitive to light areas as the CIELAB equations imply, the contrast of the soft copy image will be weaker if the black is not dark enough. Therefore, in this experiment, this reflection was taken into consideration. This reflection of the ambient light on the CRT screen was added to the colors produced by the phosphors. "R_{bk}" is the reflection ratio of the CRT screen surface, usually 0.03 to 0.05. The subscript "(CRT)" refers to the CRT monitor and "(Ambient)" refers to the ambient light. After adding this reflection, the maximum value of "Y_(CRT)" is normalized to 100. "---" indicates normalized value and subscript "n" indicates the maximum value.

$$\begin{aligned} X_{(CRT)} &= X_{(CRT)} + R_{bk} X_{(Ambient)} & \bar{X}_{(CRT)} &= \left(100/Y_{n(CRT)}\right) X_{(CRT)} \\ Y_{(CRT)} &= Y_{(CRT)} + R_{bk} Y_{(Ambient)} & \bar{Y}_{(CRT)} &= \left(100/Y_{n(CRT)}\right) Y_{(CRT)} \\ Z_{(CRT)} &= Z_{(CRT)} + R_{bk} Z_{(Ambient)} & \bar{Z}_{(CRT)} &= \left(100/Y_{n(CRT)}\right) Z_{(CRT)} \end{aligned} \quad \text{--- eq. (1)} \quad \text{--- eq. (2)}$$

2) Transformation From Tristimulus Values To Cone Signals

Then, the tristimulus values are transformed into cone signals. The Hunt-Pointer-Estevéz transformation matrix normalized to an equi-energy illuminant (E) is used here, since it is desirable to normalize the cone signals for equality for the self-luminous colors⁸.

3) Chromatic Adaptation Compensation

Finally, compensation is made for the change in adaptation according to the surroundings. The human visual system changes the cone sensitivity of each channel to get an image white-balanced as in color video cameras. Basically, the simple von Kries' adaptation model is used here, in which the signals of each channel are divided by the reference white's signals. However, the reference white point to which the human visual system adapts is investigated further here. There are two steps for the calculation of the adaptation white point; incomplete adaptation and partial adaptation.

Incomplete Adaptation

The first step in the adaptation point calculation is the compensation for the incomplete chromatic adaptation of the human visual system for the self-luminous displays. Even if the monitor is placed in a totally dark room, the human visual system will not completely adapt to a CRT monitor's white point which is significantly different from the E illuminant^{9,10,11}. Adaptation becomes less complete as the chromaticity of the adapting stimulus deviates from the illuminant E and as the luminance of the adapting stimulus decreases. The incomplete adaptation point can be expressed as below. "p_L, p_M, p_S" are the chromatic adaptation factors for the illuminant E used in the Hunt appearance model⁸.

$$\begin{aligned} \bar{L}_{n(CRT)} &= \bar{L}_{n(CRT)} / p_L \\ \bar{M}_{n(CRT)} &= \bar{M}_{n(CRT)} / p_M \\ \bar{S}_{n(CRT)} &= \bar{S}_{n(CRT)} / p_S \end{aligned} \quad \text{--- eq. (3)}$$

Partial Adaptation

The next step is the compensation for mixed chromatic adaptation. In a typical office setting, soft copy images are rarely seen under dark conditions. The room is normally illuminated with fluorescent lighting having a CCT around 4150K. The CCT of the widely-used graphic monitor's white point is much higher than this lighting, usually around 9300K. In cases where both white points are different, it was hypothesized that the human visual system is partially adapted to the monitor's white point and partially to the ambient light's white point. Therefore, the adapting stimulus for the human visual system for soft copy images can be expressed as the inter-mediate point of the two as shown in the equation below. "R_{adp}" is the adaptation ratio to the monitor's white point, "Y_{n(CRT)}" is the absolute luminance of the monitor's white point, and "Y_{n(Ambient)}" is the absolute luminance of the ambient light. When the ratio equals 1.0, the human visual system is completely adapted to the monitor's white point and none to the ambient light. This case is conceptually close to the CIELAB matching. Conversely, when the ratio is 0.0, the human visual system is totally adapted to the ambient light and none to the monitor's white. This case is conceptually close to the CIE/XYZ matching. The weighting factors (Y_{n(CRT)} / Y_{adp})^{1/3}, (Y_{n(Ambient)} / Y_{adp})^{1/3} in the equation are introduced to correspond to the luminance difference.

$$\begin{aligned}
\bar{L}_{n(CRT)} &= R_{adp} \frac{Y_{n(CRT)}}{Y_{adp}}^{1/3} \bar{L}_{n(CRT)} + (1 - R_{adp}) \frac{Y_{n(Ambient)}}{Y_{adp}}^{1/3} \bar{L}_{n(Ambient)} \\
\bar{M}_{n(CRT)} &= R_{adp} \frac{Y_{n(CRT)}}{Y_{adp}}^{1/3} \bar{M}_{n(CRT)} + (1 - R_{adp}) \frac{Y_{n(Ambient)}}{Y_{adp}}^{1/3} \bar{M}_{n(Ambient)} \\
\bar{S}_{n(CRT)} &= R_{adp} \frac{Y_{n(CRT)}}{Y_{adp}}^{1/3} \bar{S}_{n(CRT)} + (1 - R_{adp}) \frac{Y_{n(Ambient)}}{Y_{adp}}^{1/3} \bar{S}_{n(Ambient)}
\end{aligned}
\quad \text{--- eq. (4)}$$

where $Y_{adp} = \left\{ R_{adp} Y_{n(CRT)}^{1\beta} + (1 - R_{adp}) Y_{n(Ambient)}^{1\beta} \right\}^3$

With the newly-defined white points for the soft copy, the von Kries adaptation model is applied. Thus, the viewing-condition independent index: S-LMS can be expressed as below. “S” stands for the “Soft-copy” (“SCR” was used to represent “Soft-Copy Reproduction” in my previous paper ¹). For the hard copy, the simple von Kries adaptation model could be used.

$$\begin{aligned}
L^S &= \bar{L}_{n(CRT)} / \bar{L}_{n(CRT)} & L^S &= L_{(Print)} / \bar{L}_{n(Print)} \\
M^S &= \bar{M}_{n(CRT)} / \bar{M}_{n(CRT)} & M^S &= M_{(Print)} / \bar{M}_{n(Print)} \\
S^S &= \bar{S}_{n(CRT)} / \bar{S}_{n(CRT)} & S^S &= S_{(Print)} / \bar{S}_{n(Print)}
\end{aligned}
\quad \text{--- eq. (5)} \qquad \text{--- eq. (6)}$$

If necessary, S-LMS are transformed into S-XYZ using the inverse of the Hunt-Pointer-Estevéz transformation matrix normalized to illuminant E, and then to S-LAB or S-LCh.

$$\begin{aligned}
L^S &= 116 (Y^S)^{1/3} - 16 & C^S &= \sqrt{(a^S)^2 + (b^S)^2} \\
a^S &= 500 \left\{ (X^S)^{1/3} - (Y^S)^{1/3} \right\} & h^S &= \tan^{-1} \frac{b^S}{a^S} \\
b^S &= 200 \left\{ (Y^S)^{1/3} - (Z^S)^{1/3} \right\}
\end{aligned}
\quad \text{--- eq. (7)} \qquad \text{--- eq. (8)}$$

3. EXPERIMENTS

Visual experiments were performed to observe the best adaptation ratio: R_{adp} for the soft copy image matching between two monitors with different white points. A simultaneous haploscopic matching method was used in this experiment to simulate different viewing conditions for each eye. Two 21” Trinitron^(R) monitors: Sony “GDM-2000TC” were used and characterized by the method proposed by the Berns ¹² and CIE ¹³. Monitor A’s white point was set to 6530K and its luminance to 80.2 cd/m², and monitor B’s white point was set to 9370K and its luminance to 80.5 cd/m². Same experiments were replicated under two different fluorescent lamps (4183K and 3486K). A white paper set next to the monitor had a luminance of 124 cd/m² and 150 cd/m², respectively. The original image data on monitor A was transformed and reproduced on monitor B as follows;

1. RGB data are transformed to XYZ using monitor A’s device characteristics.
2. XYZ data are then transformed into S-LMS using the above adaptation model with monitor A’s viewing condition parameters at a certain adaptation ratio. In this model, necessary viewing condition parameters are; the chromaticity and the absolute luminance of the monitor’s white point, the chromaticity and the luminance of the surround.
3. S-LMS are transformed into S-LAB or S-LCh for gamut compression. Colors outside the gamut were mapped towards the achromatic axis while keeping hue lightness constant. Many gamut mapping techniques are proposed for various applications ¹⁴. However, the investigation for gamut mapping is out of scope here. Instead, we have used the images that do not have much out-of gamut colors. Then, the mapped S-LAB or S-LCh are transformed back to S-LMS.
4. S-LMS data are transformed to XYZ using the inverse of the above model with monitor B’s viewing condition parameters at the same adaptation ratio used in step 2.
5. XYZ are transformed to RGB using monitor B’s device characteristics.

Two portrait images were used for the visual experiment. The original image (512 x 341 pixels: RGB 8 bits) was displayed on the monitor A at a size of 163 mm x 108 mm with a 100% white proximal field of 5 mm wide in a 20% uniform gray background. Images at six levels of the soft copy adaptation ratio R_{adp} were reproduced on monitor B with the same proximal field and background as monitor A, and were used for the paired comparison experiment. Observers sat 70 cm from the screen and were instructed to identify the better matched reproduced image on monitor B to the original image on monitor A from a given pair. An X-window program was used for displaying and switching between the pair of images. Twenty-four color-normal observers (23 male and 1 female: ages from 26 to 55) participated.

4. RESULTS

Figures below show the result of psychophysical scale of visual matching versus the adaptation ratio at two different ambient lighting conditions. The most preferred images were at adaptation ratio of 60%, while the image at the adaptation ratio of 0% had the worst score for the both cases. This implies that the human visual system is adapted 60% to the CRT monitor and rest to the ambient light. These results were similar to our previous experiments^{1,2} of soft-copy vs. hard-copy matching experiments, in which the adaptation ratio was also 60%. The reproduced soft copy image at 60% adaptation ratio had acceptable match to the original image on a different CRT and had much better reproduction than CIE/XYZ-matched or CIELAB-matched images.

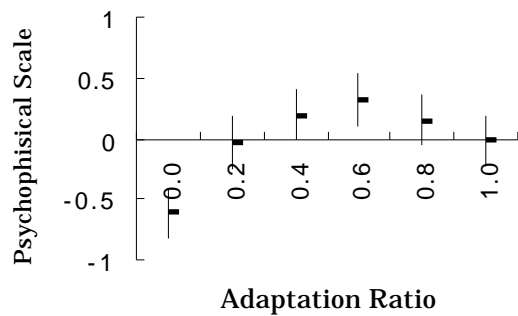


Fig. 1 Adaptation Ratio at 4183K Ambient Light

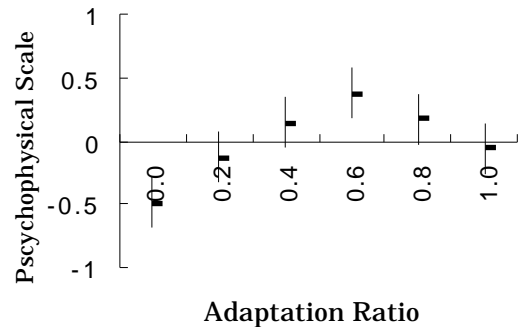


Fig. 2 Adaptation Ratio at 3486K Ambient Light

5. CONCLUSION

The experimental results indicated that the human visual system is 60% adapted to the monitor's white point and 40% to the ambient light. These appearance-matched images had better matching than the reproduction of current CMSs. Therefore, this adaptation model can improve the soft copy reproduction of current CMSs and could be used as an interchange space for from any device to another.

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