A Study on how chromatic adaption affects human visual performance of display

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Abstract

We studied the human visual performance with PDP and LCD to clarify the relationships between viewer preference and chromatic adaption. In this paper, optical performance of the display is measured mechanically based on standard. The human visual performance about the display color image quality trough optical process is represented numerically based on CIECAM02. By comparing these results with the result of the questionnaire, performance of the display can be evaluated in detail.

1. Introduction

Most studies on enhancement of human perceptive image quality in display are focused on intensity of light. It can be simply described in several optical index, such as luminance, contrast and color. Among these values, the color is most difficult to measure in one way. Because color perception not only occurs in the human eyes but is also a response to ambient light, separate color descriptions are necessary for the external, physical light stimulus and the subjective color perception. The techniques of photometry allow description of the intensity of a light stimulus as it appears to human vision, and colorimetry translates the stimulus into a color specification. However, they are limited to the trichromatic outputs from luminance meter, those data generated by the photoreceptor response are only small index of color information. They are isolated color samples which exclude human visual system. With those electro-optical values, we cannot model many of the contextual effects of color perception, including luminance adaptation, chromatic contrast or chromatic assimilation that arises in real world viewing condition. The earliest color models only described colors that were viewed or compared in a standardized viewing situation. In the recent few decades, more ambitious color models have been developed that adjust the color space to represent the effects of the visual context and viewing conditions. This raises them to the status of color appearance models that predict a wide range of real world color experiences. The current example of this approach is CIECAM02. CIECAM02, which is developed by Nathan Moroney, Mark Fairchild, Robert Hunt and others [2], represents a culmination and also an end point in the development of color appearance models. So, in this paper, we studied the human visual performance of watching TV display by comparing subjective viewer preference measurement and numerical chromatic adaption of CIECAM02 color appearance model.

2. Experimental

The study was conducted by physical measurement and subjective evaluation with six LCD and PDP TVs to clarify the relationships between viewer preference and chromatic adaption. Physical color measurements and subjective color descriptions are only correlated, in the sense that one approximates but does not define the other. The CIECAM calculations are quite complex when compared to CIELAB. CIECAM also requires more starting information. Measurement of starting optical data of LCD and PDP TVs was based on VESA FPDM with luminance meter. Chromatic adaptation modeling was conducted using matrix to change CIEXYZ coordinates into CIECAM coordinates. The process to change CIEXYZ coordinates into adapted CIEXYZ coordinates is affected by CIE XYZ coordinates of white standard. In this process, the XYZ tristimulus values for the color area being modeled, the $X_wY_wZ_w$ tristimulus values for the white standard or illuminant, and the adaptation luminance Y_b of the adjacent color background, equivalent to the standardized luminance were obtained. In addition, the photometric information-the average luminance of the visual environment or surround- L_A was measured. With those input, we can deduct out luminance response compression factor.

$$k = \frac{1}{5L_A + 1}$$

$$F_L = 0.2k^4(5L_A) + 0.1(1-k^4)^2(5L_A)^{1/3}$$

$$(F_L:\ \text{luminance response compression factor})$$

Using CIECAM02 convert matrix, we also can figure out luminance coefficient which can be utilized in color adaption.

$$D = F[1 - \left(\frac{1}{3.6}\right)e^{\left(\frac{-(L_A+42)}{92}\right)}]$$

$$(D:\ \text{luminance adaptation})$$

Adjustments for luminance adaptation (D) are made on the color and illuminant RGB values, resulting in post adaptation values for the color area (RcGcBc) and the illuminant. This is the point where the illuminant tristimulus values are used to perform a Von Kries transform for chromatic adaptation, shown below for the R value. If we settle the white standard or illuminant tristimulus value as normalized index 100, color adaption response can be defined as below. The same adjustment is performed on the Gc and Bc values.

$$R_C = \left[\left(\frac{100D}{R_W}\right) + (1-D)\right]R$$

$$(R_W:\ \text{tristimulus value of white illuminant})$$

There is complete adaptation to the illuminant when D = 1. Otherwise this transform decreases or increases the cone output to match the chromaticity of the illuminant, in proportion to the degree that adaptation only partly occurs. That is, D < 1 when the surround is darker than the image, and the difference between the image and surround luminance prevents complete adaptation. Now, for mapping CIECAM02 area, we should deduct out a,b coordinates which can be plot. The post adaptation $R_cG_cB_c$ values are converted back into XYZ tristimulus values. Parallel transformations are done to retrieve the illuminant XYZ values. The post adaptation XYZ values are converted into a specific type of equal area cone fundamentals (based as Hunt Pointer Estevez theory) that denoted R'G'B'. Finally, a response compression is applied to the R'G'B' cone fundamentals. This compression is approximately hyperbolic with a minimum value near zero and an upward slope that changes in relation to the level of surround luminance L_A, expressed as the response compression factor F_L. The calculation is shown below for the R' value, the same adjustment is made to the illuminant R'wG'wB'w values.

$$R'_a = \frac{400\left(\frac{F_L R'}{100}\right)^{0.42}}{27.13 + \left(\frac{F_L R'}{100}\right)^{0.42}} + 0.1$$

With $R'_aG'_aB'_a$ values, we can deduct two dimension color coordinates based on former color appearance model CIELAB formula as below.

$$a = R'_a - \frac{12G'_a}{11} + B'_a/11$$

$$b = (1/9)(R'_a + G'_a - 2B'_a)$$

Therefore, by calculating area of color adaption coordinates in each RGB, we can figure out how chromatic adaption affects human visual performance of display in quantitative ways.

Subjective evaluation was conducted by questionnaire and dealt with psychological statistics. Adaptive color preference was defined by questionnaires which participants scored after viewing several Flat Panel Displays.

3. Results and discussion

Fig. 1 and Fig. 2 show that the change of RGB in each color adaption calculating process under different illuminant condition. Each figure starts from the basic tristimulus values RGB, then through the post adaptation values for the color area (RcGcBc), finally ends up to converted human eye color adaption fundamentals (based as Hunt Pointer Estevez theory) that denoted Ra'Ga'Ba'. Fig. 1 shows the result of high illuminant viewing condition. In near 300cd/m^2 illuminance, chromatic adaption brings severe loss in process of CIECAM02 coordinates conversion. It means that high illuminant watching condition can distort display color reproduction. This assumption is much evident in Fig. 2. Fig. 2 shows that low illuminant viewing condition result, below 10cd/m^2. In dimmed illuminant condition, there also existed regression in color appearance, the distortion by color adaption process was much smaller than that of more bright condition. Especially, we found out that the higher frequency and smaller wavelength color, i.e. blue, color adaption was much dependent to the external illuminant. From both figures, it was proven to be the critical factor which determined the viewer color adaption should be segmented by illuminant condition. The amount of how much color coordinates of white illuminant affects on human eye chromatic adaption is determined by adapt constant. If adapt constant is close to zero, we can exclude the illuminant effect, that is adapted CIECAM02 color coordinates are the same to original CIE XYZ coordinates. If adapt constant is close to one, effect of color coordinates of white illuminant becomes dominant. Adapted constant is determined by adapted luminance, which is related to viewing condition illuminant. Usually high luminance displays show high absolute value of CIE XYZ coordinates and large color gamut area metric, so they have an abundance of colors. In order that gamut area metric is preserved in chromatic adaption, adapted luminance should be properly set so that effect of color coordinates of white external illuminant is minimized. In other words, displays with low luminance can increase its gamut area metric after chromatic adaption if adapted luminance properly set so that effect of color coordinates of white external illuminant is maximized to enhance the original displays luminance and color reproduction.

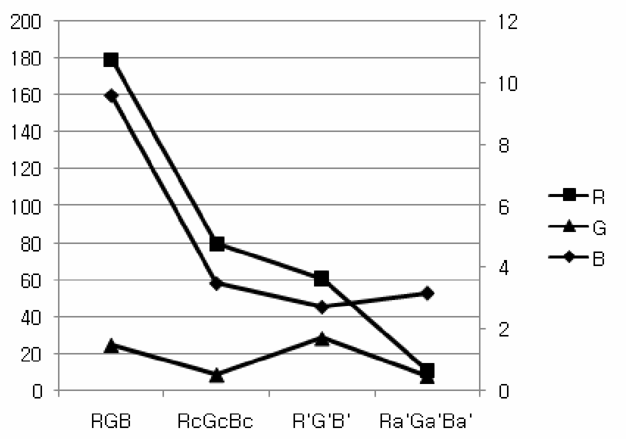

Fig. 1. Change of CIE coordinates in chromatic adaption progress near 300cd/m^2 (white).

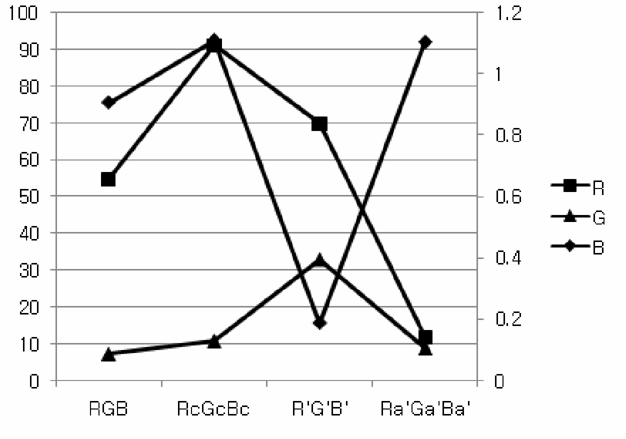

Fig. 2. Change of CIE coordinates in chromatic adaption progress below 10cd/m^2 (white).

In Fig. 3, six TVs (three LCDs and three PDPs) color gamut percentile were plotted. From the CIE1931 XYZ color gamut areas in box and full pattern which were measured with luminance meter, CIECAM02 conversion area metric and color adaption area metric in 300cd/m^2 illuminant were calculated in order. The color appearance model area by CIECAM02 shows quite different tendency compared to plain electro-optical results. However, another color appearance index, the illuminant-effect color adaption gamut, is good accord with the box pattern optical data. Although the numerical values and the margin show disparity, the outside color and luminance effect which can be occur in measuring box pattern would give a similar effect likewise illuminant color adaption.

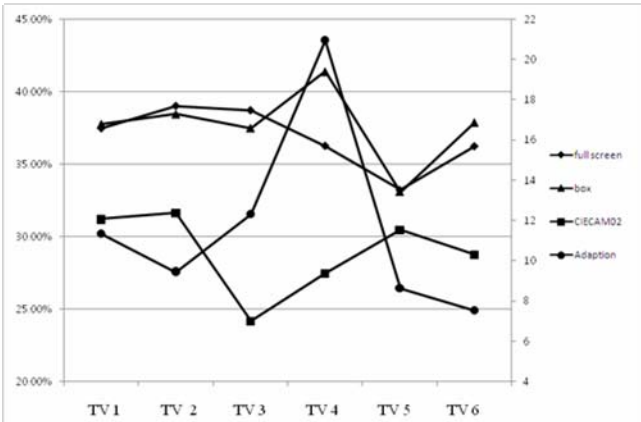

Fig. 3. Color gamut area in CIE1931 (Full, Box pattern), CIECAM02 and after color adaption conversion. (300cd/m^2).

Subjective evaluation result is correspondent to the CIECAM02 color appearance gamut metric. Fig. 4 is the questionnaire results dealt with statistics. Adaptive color preference was defined by questionnaires which participants scored after two hours watching of six Flat Panel Displays.

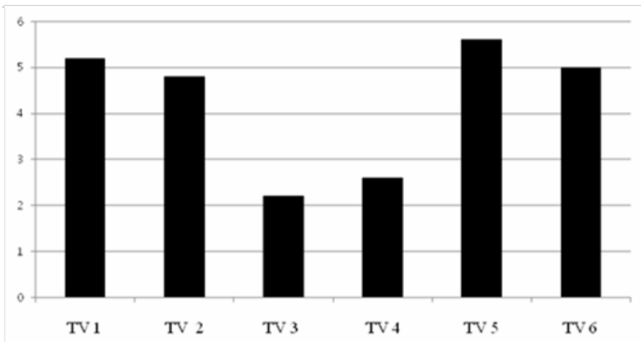

Fig. 4. Subjective color appearance scores by questionnaire and statistical method.

The visual color preference and intensity were scored as point from 1 to 6. The viewer's color intensity preference shows same tendency to the CIECAM02 color mapping gamut in Fig. 3. Even if the illuminant color adaption gamut does not exactly agree to the human color preference, from the TV 3 and TV 4 result in Fig. 3 and Fig. 4, we can assume that the excessively illuminant-dependent TVs viewer color preference is lower than others. It supports the idea that adapted luminance should be properly set so that effect of color coordinates of white external illuminant is minimized. In advance, we can find objective standards of external illuminant to enhance the human visual performance affected by chromatic adaption.

4. Summary

Fundamentally color depends on context, and context can dramatically change the appearance of lights and surfaces. In this paper, for measuring effects of the visual context and viewing conditions, context parameters (reflected illuminance in the surround matches the illuminance on the color area, response compression in image lightness, brightness and chroma caused by background lightness) were calculated by color appearance model CIECAM02. Much of the development work leading up to CIECAM02 involved the choice of chromatic adaptation calculations that gave accurate and invertible results. No matter how much improvement we make in display industry, the main role of the display technology is to make an image on the screen more real as human eye perception. In this paper, we suggested the basic idea about how color perception and adaptation are made in various illuminant conditions, at a time, showed how chromatic adaption affects human visual performance in watching display. The viewer's color intensity preference shows same tendency to the CIECAM02 color mapping gamut. We also suggest the idea that excessively illuminant-dependent TV's viewer preference is lower than the others. Color is the major part of the image, so this kind of research contributes to enhance display's human perceptive image quality.

Acknowledgement

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5. References

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