Effect of ambient light source for the appearance of color image on CRT monitor

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ABSTRACT

Color images are usually viewed on CRT monitor screen under ambient light sources. The feeling for reproduced color on CRT monitor depends on white point of ambient light source and the CRT monitor screen’. Therefore, if the effect of ambient light source is not considered, then the reproduced color does not match the intrinsic color. This paper proposes a method to investigate the effect of ambient light source on color appearance of a CRT monitor which is positioned in a room illuminated by an experimental light source.

The investigation for the effect of ambient light consists of two elements. One is the flare effect that the reflection on the CRT monitor screen which produced by the ambient light source. Another is the change of adaptation in white point. When the images are viewed on a CRT monitor screen under ambient light, the state of adaptation is affected by both the white point of the monitor and ambient light source. Therefore, these two effects were analyzed in the experiments.

Keywords: flare effect, color adaptation, adaptation model, adaptation white point, tone-curve correction, gamma correction

1. INTRODUCTION

International color consortium (ICC) profiles^ are used in color management systems (CMS) as the necessary information for the color characteristic of devices. Most of current CMSs on the PC market guarantee the same color only if one sees color under specific controlled viewing condition’. However, current CMSs have some inevitable technical problems. If one sees color under a different viewing condition, the reproduced color does not match the original. The network environment enables users to send color images from one place to another with different viewing conditions. In such cases, it is impossible to achieve the same color appearance with only these CMSs Color images are usually viewed on CRT monitor screen under ambient light source. In a typical office environment, computer monitors with correlated color temperature (CCT) of 9300K or 6500K is widely used under fluorescent or incandescent lights. In these cases, perception of the reproduced color on the CRT monitor depends on the white point of ambient light source and white on the CRT monitor.

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screens. Therefore, if the effect of ambient light source is not considered, the reproduced color does not match the original color.

In this paper, the effect of ambient light source is analyzed as the color appearance of the CRT monitor which was positioned in a room illuminated by experimental light source, incandescent or fluorescent light. The investigation for the effect of ambient light consists of two elements. One is the flare effect that the reflection on the CRT monitor screen which is produced by the ambient light source. The other is the change of adaptation white point. When the images are viewed on a CRT monitor screen under ambient light, the state of adaptation depends on both the white point of the monitor and the ambient light source.

At first, the reflection on the CRT monitor screen that is produced by the ambient light source is considered. In this experiment, the amount of reflection of ambient light was measured at the center of the CRT monitor by CS-100 of Minolta without ambient light, and then with ambient incandescent, or fluorescent light source. According to the experimental results, measured tri-stimulus values of X, Y and Z of the reflection for the ambient light on the CRT monitor screen are linearly proportional to the tri-stimulus values of X, Y and Z for light source.

The second effect, change of adaptation white point, is considered and tested as the luminance of light source was controlled at various levels. The observers adjusted color on the CRT under ambient light source to find out the color matching on the CRT without ambient light source. This paper investigates the effect of chromaticities and luminance of ambient light source on CRT color by color matching experiment. The relationship between shift ratio of the adaptation state, and chromaticities and luminance of the light source, was obtained.

2. Conventional algorithm

When a CRT monitor is viewed under ambient light, the color appearance of the CRT is influenced by chromaticity and luminance of the ambient light source. This topic was studied by Fairchild, Brainard, Naoya Katoh and Hunt. In this paper, we review Hunt’s experiment, Brainard’s achromatic matching experiment and, the mixed chromatic adaptation for self-luminous display of Naoya Katoh.

2.1 Experiment by Hunt

Viewers primarily watch a television under the surrounding light source of an incandescent or a fluorescent light. When the human visual system has been adapted chromatically under the different surrounding light, the same chromaticities elicit quite different color appearances. When we watch television, we watch the television under a fluorescent or an incandescent light.

Figure 1 shows the result of this experiment. In Figure 1, ● is white point of the television screen and ■ is white point of an incandescent light source, and ◆ is the adaptation white point. Experimental results indicate that adaptation white point
exists between the white point of television screen and the white point of an incandescent of u-v space. Furthermore, adaptation white point shifts toward that of the ambient light source according to the increase of luminance level of the ambient light source.

Figure 1. Adaptation white point when we watch television under an incandescent light source.

2.2 Experiment by Brainard

Brainard performed an achromatic matching experiment\(^4\) for color appearance on CRT monitor considering the effect of ambient light source. One eye see an original achromatic patch on CRT monitor screen in a dark room, the other eye sees various patches on the CRT monitor screen under ambient light source (SMH method\(^{11-13}\)). An observer chooses patch which most resembles. In this experiment, the adaptation white point in human vision is between the monitor's white point and the white point of the ambient light source.

2.3 Mixed chromatic adaptation for self-luminous display of Naoya Katoh

Naoya Katoh performed the experiment about the effect of ambient light on the color appearance of softcopy images in a typical office environment, used a computer graphic monitor with a correlated color temperature of 9300 K, widely used under F6 fluorescent light of 4150 K CCT. In such a case, the human visual system is partially adapted to the CRT monitor's
white point and partially to the ambient light. A new adaptation model, S-LMS, was proposed to compensate for the mixed chromatic adaptation in Naoya Katoh's paper. The adaptation modeling used essentially consists of four stages. The first stage is compensation for reflection of the CRT monitor screen, the second stage is transformation from tri-stimulus values to cone signals, the third stage is compensation for chromatic adaptation. The last stage is application of mixed adaptation model, S-LMS. Experimental results indicated that the human visual system is 60% adapted to the monitor’s white point and 40% to ambient light when viewing softcopy images. This adaptation ratio itself was found to be independent of the luminance level of the ambient light source.

3. PROPOSED ALGORITHM

This paper investigates the effect of ambient light source on the color appearance of a CRT monitor which was positioned in a room illuminated by experimental incandescent, or fluorescent light source. The investigation for the effect of ambient light consists of two elements. One is flare effect which is the reflection on the CRT monitor screen which is produced by the ambient light source. Since the reflection on the CRT monitor screen is produced by ambient light, black does not have the same chromaticity as the white point of the CRT monitor. The other effect is change of adaptation white point. When the images are viewed on a CRT monitor screen under ambient light, the state of adaptation is affected by both the white point of the monitor and the ambient light source. Because our eyes are not fixed on the CRT monitor screen all the time, humans see the surroundings at intervals. In this paper, adaptation modeling used consists of three essential stages. The first stage is characterization of the CRT monitor and the second one is the consideration for the reflection of ambient light. The last one is consideration of adaptation white point change.

3.1 Characterization of CRT monitor

The CRT monitor used in the experiment was a Samsung SyncMaster 700p. This monitor was characterized by the method proposed by Berns14 and by CIE15. The model mainly consists of two stages: the tone-curve correction (gamma-curve correction) for cathode ray tube characteristic and the additive color mixture of red, green, and blue phosphors. A Minolta CS-100 was used for the measurements of 24 color patches of Macbeth Color Checker. The first stage is tone-curve correction expressed as follows:

\[
R = k_{r, \text{gen}} \left( \frac{dr}{255} \right) + k_{r, \text{eff}, r} \\
G = k_{g, \text{gen}} \left( \frac{dg}{255} \right) + k_{g, \text{eff}, g} \tag{1}
\]
\[ B = k_{b, \text{ref}} \left( \frac{db}{255} \right)^{y_b} + k_{b, \text{eff}} \ldots \]

The second stage is tone-curve correction expressed in equation (2).

\[
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
= \begin{bmatrix}
X_R & X_G & X_B \\
Y_R & Y_G & Y_B \\
Z_R & Z_G & Z_B
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\] (2)

3.2 The reflection of ambient light on the CRT monitor screen

The effect of ambient lights was investigated and the effect consists of two components. One is the flare effect which is the reflection on the CRT monitor screen produced by the ambient light source. The black on the CRT screen will not be dark enough because the reflection of ambient light still exists and the chromaticity of white point on the CRT screen under ambient light is different from the white point on the CRT screen without ambient light. In this experiment, the amount of

Figure 2. The reflection of ambient light on the CRT monitor screen.
reflection for ambient light was measured at the center of the CRT monitor by CS-100 of Minolta in two cases as with and without ambient light source, i.e., incandescent or fluorescent light source. A Samsung SyncMaster 700p CRT monitor with correlated color temperature (CCT) of 9300 K and 6500 K was used in the experiment. Figure 2 shows the reflection of the ambient light on the CRT monitor screen. The measured XYZ are as follows:

$$\begin{bmatrix} X_{(CRT+L)} \\ Y_{(CRT+L)} \\ Z_{(CRT+L)} \end{bmatrix} = \begin{bmatrix} X_{(CRT)} \\ Y_{(CRT)} \\ Z_{(CRT)} \end{bmatrix} + \begin{bmatrix} K_X & 0 & 0 \\ 0 & K_Y & 0 \\ 0 & 0 & K_Z \end{bmatrix} \begin{bmatrix} X_{(L)} \\ Y_{(L)} \\ Z_{(L)} \end{bmatrix},$$

where $X_{(CRT)}$ is tri-stimulus X of CRT monitor screen, and $X_{(L)}$ is tri-stimulus X of the ambient light and $X_{(CRT+L)}$ is tri-stimulus X of reflected light of CRT monitor screen with ambient light source. $K_X$, $K_Y$ and $K_Z$ are the reflectance factors of the CRT monitor screen. In this experiment, individual values are 0.0745, 0.0777 and 0.0775 respectively. According to the experimental results, each tri-stimulus values X, Y and Z of the reflection of ambient light on the CRT monitor screen are multiplication of a constant and each tri-stimulus value X, Y and Z of ambient light source.

### 3.3 Change of adaptation white point

![Figure 3. White point of adaptation.](image)
The second effect is the change of adaptation white point of human vision. In a practical situation, when an image is viewed on a CRT monitor screen under a certain viewing conditions, the state of adaptation is affected by both of the white point of the monitor and ambient light, and these two white points are different from each other. Also, our eyes are not fixated on the CRT monitor screen all the time: they see the surroundings at intervals. Therefore, our state of chromatic adaptation is not fixed at a single state. Figure 3 shows the adapted white point of human vision and the white point of adaptation is located between the white point of the CRT monitor (added reflection of ambient light) and of ambient light in u'-v' space where ■ denotes the white point of ambient light, ▲ denotes the white point of CRT monitor, ● denotes the white point of CRT monitor (added reflection of ambient light) and ○ represents the white point of adaptation.

In this experiment, incandescent and fluorescent lights with various luminance levels were used as experimental light sources in memory matching. The observers adjusted color on the CRT under surrounding ambient light source to find color matching on the CRT under no surrounding ambient light source. According to the chromaticity distance between the chromaticities of the CRT white and those of light source in u'-v' color coordinate and luminance ratio (luminance of a white paper on the CRT/luminance of CRT white), Table 1 shows the adaptation ratio for the ambient light. Formulation of adaptation ratio was established from the results of Table 1. The parameters for this formula were distance ($D_{u'-v'}$) between the chromaticity of ambient light and CRT monitor (added reflection of ambient light) and luminance ratio ($Y_{ratio}$) of ambient light to CRT monitor (added reflection of ambient light). The formula is as follows by using ratio parameter $R_{(adp)}$:

\[
\begin{bmatrix}
  u'_{(adp)} \\
  v'_{(adp)}
\end{bmatrix}
= (1 - R_{(adp)}) \begin{bmatrix}
  u'_{(Mon+L)} \\
  v'_{(Mon+L)}
\end{bmatrix}
+ R_{(adp)} \begin{bmatrix}
  u'_{(L)} \\
  v'_{(L)}
\end{bmatrix}
\]

(4)

where $u'_{(Mon+L)}$ and $v'_{(Mon+L)}$ are chromaticities of the white point of monitor (added reflection of ambient light), $u'_{(L)}$ and $v'_{(L)}$ are chromaticities of ambient light and $u'_{(adp)}$ and $v'_{(adp)}$ are chromaticities of white point for the adaptation of human vision. $R_{(adp)}$ is the adaptation ratio for ambient light and is shown is Table 1. The Adaptation ratio for ambient light is as follows:

\[
R_{(adp)} = (1.8Y_{ratio} + 0.37)D_{u'-v'} + 0.124Y_{ratio},
\]

(5)
where

\[ Y_{\text{ratio}} = \frac{Y_{(L)}}{Y_{(L_0+L)}} \],

\[ D_{n'w'} = \sqrt{(u'_{(L_0+L)} - u'_{(L)})^2 + (v'_{(L_0+L)} - v'_{(L)})^2} \].

Table 1 Adaptation ratio for ambient light according to the luminance ratio and chromaticity distance

<table>
<thead>
<tr>
<th>(D_{n'w'})</th>
<th>(Y_{\text{ratio}})</th>
<th>Adaptation ratio for ambient light</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0195</td>
<td>0.4652</td>
<td>7</td>
</tr>
<tr>
<td>0.0438</td>
<td>0.4832</td>
<td>12</td>
</tr>
<tr>
<td>0.0442</td>
<td>0.3493</td>
<td>10</td>
</tr>
<tr>
<td>0.0820</td>
<td>0.4375</td>
<td>15</td>
</tr>
<tr>
<td>0.0829</td>
<td>0.2369</td>
<td>10</td>
</tr>
<tr>
<td>0.0825</td>
<td>0.3371</td>
<td>12</td>
</tr>
<tr>
<td>0.1074</td>
<td>0.4544</td>
<td>17</td>
</tr>
<tr>
<td>0.1088</td>
<td>0.2462</td>
<td>12</td>
</tr>
<tr>
<td>0.0443</td>
<td>0.6024</td>
<td>15</td>
</tr>
<tr>
<td>0.0198</td>
<td>0.5803</td>
<td>10</td>
</tr>
<tr>
<td>0.0198</td>
<td>0.4563</td>
<td>7</td>
</tr>
<tr>
<td>0.0198</td>
<td>0.3362</td>
<td>5</td>
</tr>
</tbody>
</table>

And adaptation white point \(Y_{(\text{adapt white point})}\) is as follows:

\[ Y_{(\text{adapt white point})} = \left( \frac{1 - R_{(\text{adapt})}}{R_{(\text{adapt})}} \right) Y_{(L)}^{1/3} + \frac{R_{(\text{adapt})}}{R_{(\text{adapt})}} Y_{(L)}^{2/3} \]  

(6)

\[
\begin{bmatrix}
  u' \\
  v'
\end{bmatrix}
= \frac{1}{-2x + 12y + 3} \begin{bmatrix}
  4x \\
  9y
\end{bmatrix}.
\]

(7)
The tri-stimulus values $X$, $Y$ and $Z$ for the white point of adaptation can be obtained from equation (4) and equation (6) using equation (7) and equation (8).

\[
\begin{bmatrix}
  x \\
  y \\
  z
\end{bmatrix} = \frac{1}{X + Y + Z} \begin{bmatrix}
  X \\
  Y \\
  Z
\end{bmatrix}
\]  

(8)

4. CONCLUSION

The reproduced color on a CRT monitor depends on the color of the ambient light source as well as the color on the CRT monitor screen. Therefore, if the effect of ambient light source is not considered, then the reproduced color does not match the intrinsic color. This paper proposed the method to investigate the effect of ambient light source on color appearance of a CRT monitor which is positioned in a room illuminated by experimental light source. The investigation for the effect of ambient light consists of two elements. One is flare effect that the reflection on the CRT monitor screen produced by the ambient light source. The other is change of adaptation in white point. By the proposed experiment, ratio for the ambient light and human perception is calculated and this ratio can be used in reproducing more consistent color appearance of CRT monitor when it is viewed under various ambient light sources.

REFERENCES


