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Study on perceptible and acceptable ranges for color gamut of transparent displays

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Abstract

This paper presents results of perceptible and acceptable ranges for color gamut change of transparent liquid crystal display (LCD) by luminous sources. Color gamut of transparent LCD can be changed by external luminous source because LCD cannot emit by itself. In this paper, perceptible and acceptable ranges to optimize color gamut for transparent LCD were found by psychophysical experiments. External luminous sources which have color temperatures of 3000, 5000 and 6500K were used. As a result, the differences of perceptible and acceptable ranges of color gamut using light sources are about 3% and 18% respectively. In addition, the differences of perceptible and acceptable range were investigated according to illuminance of external luminous. The difference of perceptible ranges does not affect the illuminance intensity. When the intensity of illuminance was high, the acceptable range was decreased than low illuminance. When the color gamut of transparent LCD has decreased within acceptable ranges, most observers can permit the image quality regardless of light source. In other words, transparent LCD which has somewhat narrow color gamut can be permitted.

Keywords : Transparent display, Color characteristic, Liquid crystal display, Color gamut, Perceptible ranges, acceptable ranges, image quality

1. Introduction

According to progress of display industry, new displays are required to have flexible and transparent properties. Therefore, related researches about new display technology have been conducted actively [1, 2]. Especially, transparent display has attracted increasing interest for various applications such as cooler doors, windows, exhibitions and advertisements. There are extensive studies from fabrication to user interaction[3-7]. Although see-through property is significant feature of transparent display, the main function is to display information with high image quality. It is, therefore, required to study about image quality of transparent display. C.H. Lin et al[8] studied color gamut of transparent display by changing the transmittance of new sub-pixel structure. However, they did not consider the usage environment and the image quality of the transparent display. According to usage environment, the image quality of transparent display significantly affected, because transparent liquid crystal display (LCD) needs external luminous source. Color characteristics of transparent LCD depend on spectrum of light source. Therefore, additional studies for image quality of transparent display are required. In this paper, the effect of luminous source on chromaticity of transparent LCD is investigated. Human perceptual characteristics of color characteristic for transparent display are also studied under ambient conditions of luminous sources having different spectrum in order to optimize image quality of transparent LCD.

2. Electro-Optical characteristic of Transparent LCD display

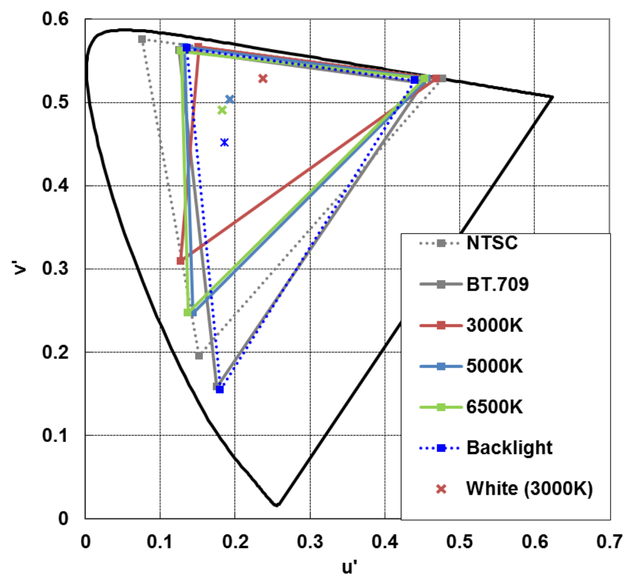

Figure 1. Color gamut of transparent LCD.

The chromaticity coordinate values were measured under external light sources having different spectrum, and color reproduction ratio to BT.709. were analyzed. A forty seven-inch transparent in-plane switch (IPS) panel LCD which shows normally black mode was used. Electro-optical characteristic of transparent LCD was measured using light measuring device (LMD) (CS-2000, Konica Minolta). External luminous sources which have color temperatures of 3000, 5000 and 6500K were used. Each of luminous sources was installed behind transparent LCD display panel to measure. The measurement results are presented in Table 1.

Color gamut under illumination having color temperature of 3000K is 64 percent compared with color gamut of BT.709 using u'v' color coordinates. Color gamut under illumination of 5000K has higher value as 80 percent and one under illumination of 6500K is 78 percent.

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Table 1. Measurement Results of Color Reproduction Range.

Color temperature of illuminous source	Color reproduction range (to BT.709)
3000 K	64 %
5000 K	80 %
6500 K	78 %
9500 K (Backlight)	95%

In General, as color temperature of luminous source becomes lower, the blue color coordinate values are more affected. The color coordinate values of white are followed color temperature of the luminous source. Figure 1 shows the color gamut of transparent LCD under three luminous source conditions in u'v' color chromaticity diagram. Figure 2 shows the spectrum of luminous sources through transparent LCD. Color gamut is reduced as the light source has lower color temperature than 10,000K since transparent LCD used in this experiment was designed to 10,000K backlight. White spectrum of 3000K has a reliably high energy of short-wavelength than 6500K. Color gamut of transparent LCD highly depends on the spectral distribution of the light source and designed color spectrum. It is required to consider the matching between the light source and transparent LCD.

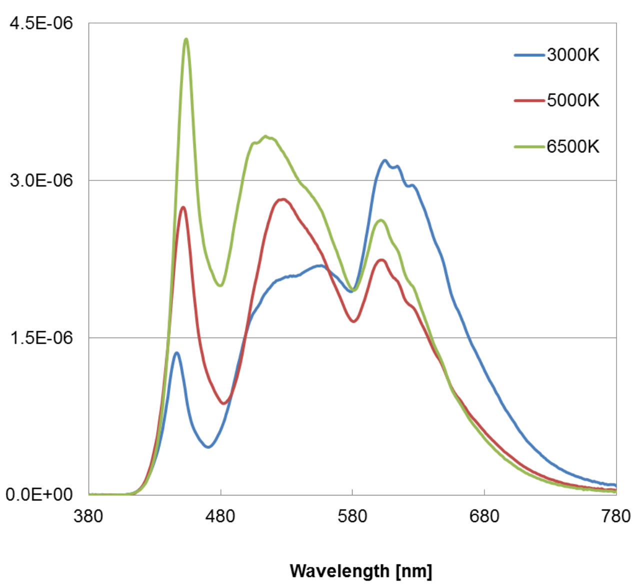

Figure 2. White spectrum of three conditions luminous for Transparent LCD.

2. Psychophysical Experiment

2.1 Experimental Methods

Visual assessment has been carried out. Twelve observers who are experts in the field of image quality participated in the psychophysical experiments(7 males and 5 females). Illuminance that is considered by transmittance of LCD was set as 2000 lx. Since the transparent LCD generally has a low transmittance, the illuminance level must be sufficiently high. The viewing distance was set to 3H, where H refers to the height of the display. Then, twenty three test images were selected considering their color distribution of red, green, blue, cyan, magenta, yellow and memory colors as presented in Figure 3. Each set of color image composed from a low value of saturation to a high value of one. Observers were asked to answer following questions in two-alternative forced choice (2AFC):

Q1. Do you distinguish the difference of the color gamut of two images?

Q2. If you feel the difference, you can accept the difference of color in right image?

Participants have to answer whether they can notice or not. Also, they can accept the difference level between the original test image and rendered image which has reduced color gamut. From the answers, JND and JAD to reduction of color gamut were determined at the point having probability of 0.5. In this case, JND is a psychological term which stands for the smallest intensity difference that can identify the differences between the two stimuli. This refers to the difference threshold and the law of Weber. JAD means the difference between the two stimuli that can be accepted by observers.

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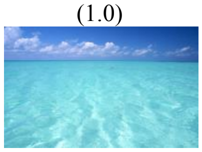
(0.85) (0.38)

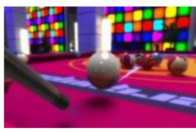
Cyan

(1.0) (0.94)

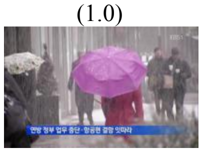


(0.51)

Magenta




(1.0) (0.69)



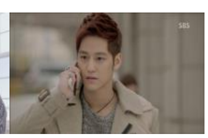
(0.3)

Yellow


(0.79) (0.73)

(0.66)

Skin

(0.48) (0.44)

(0.17)

Figure 3. Test images for perceptible/acceptable psychophysical experiments

Second visual assessment has been carried out in the fixed CCT of external luminous. Participants answered perceptible and acceptable color reproduction rate for various illuminance conditions. The condition of illuminance composed of five levels: 400, 1500, 1000, 2000 and 4000 lx. Participants received similar questions of the first visual assessment.

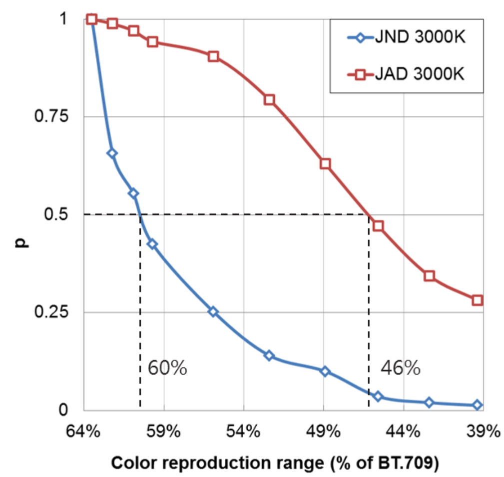
Q1. Do you distinguish the difference of the color gamut of two images for various illuminance conditions?

Q2. If you feel the difference, you can accept the difference of color in right image for various illuminance conditions?

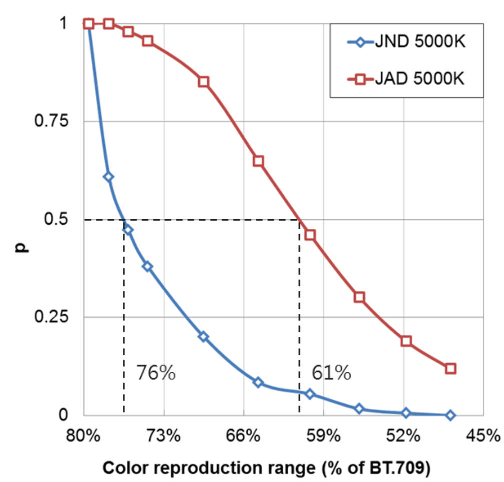
As previous experiment, both JND and JAD of color gamut were determined at the point having probability of 0.5.

Experimental Results

Perceptible and acceptable ranges were investigated through experiments. Perceptible and acceptable ranges were calculated as 50% criteria following Torgerson, 1958[9]. First, in 3000K, color reproduction range that 50 percent response rate of participants noticed color gamut reduction of transparent LCD is 61 percent. Acceptable color reproduction range in 3000K is 46 percent. Second, in 5000K, noticeable color reproduction range is 76 percent and acceptable color reproduction range is 61 percent. Lastly, noticeable color reproduction range is 75 percent and acceptable color reproduction range is 60 percent in 6500K.



(a) JND and JAD in 3000K



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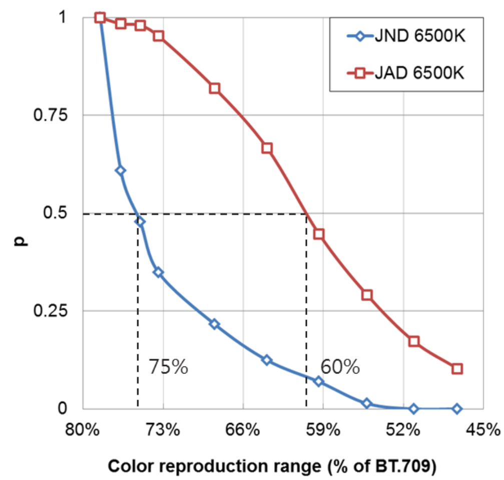
(b) JND and JAD in 5000K



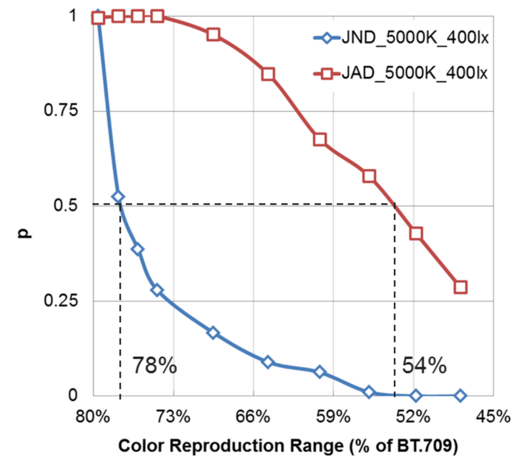
(c) JND and JAD in 6500K

Figure 4. Perceptible and acceptable ranges of color gamut reduction.

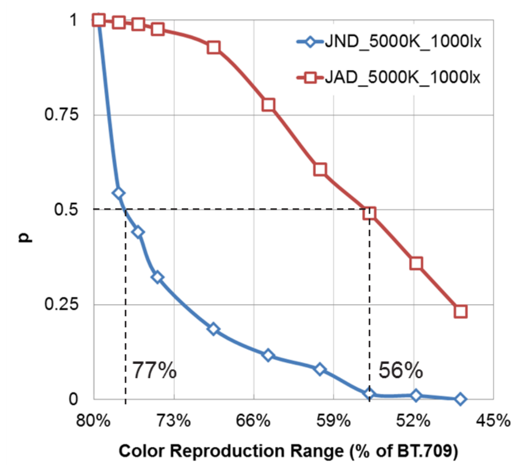
Figure 4 shows the results of Perceptible and acceptable ranges in three conditions of color temperature. The results of psychophysical experiment show that perceptible range is 3 to 4 percent, while acceptable range is 18 to 19 percent regardless of color temperature of luminous sources. Table 2 shows a specific color reproduction range value of JND and JAD.

Table 2. Perceptible and acceptable ranges of color gamut reduction.

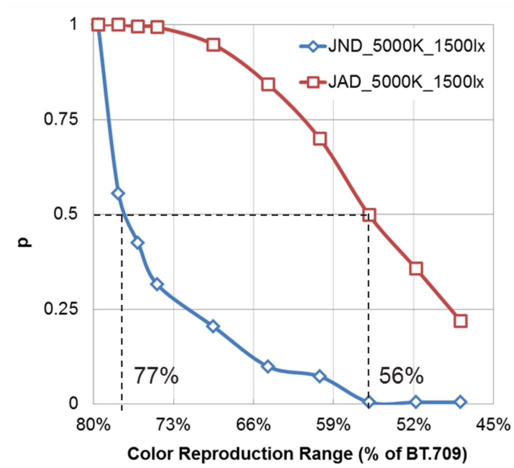
CCT of External Luminous	Color Reproduction Range	Limit of perception	Limit of acceptance
3000K	64%	60%	46%
5000K	80%	76%	61%
6500K	78%	75%	60%



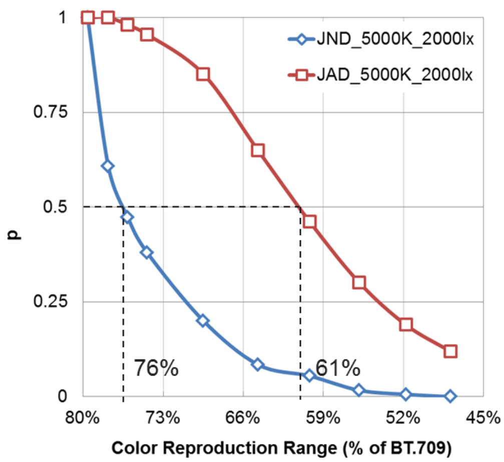
(a) JND and JAD in 400lx (5000K)



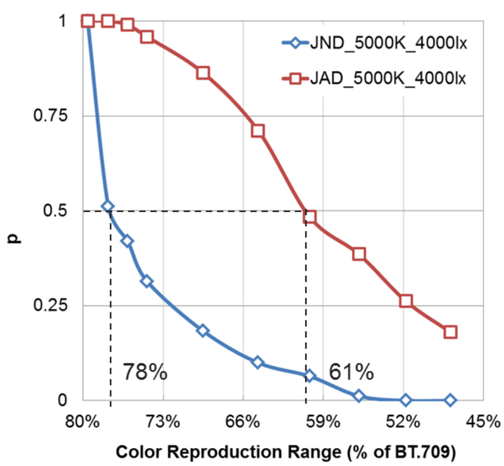
(b) JND and JAD in 1000lx (5000K)



(c) JND and JAD in 1500lx (5000K)



(d) JND and JAD in 2000lx (5000K)



(e) JND and JAD in 4000lx (5000K)

Figure 5. Perceptible and acceptable ranges of color gamut reduction in various intensities of illuminance.

Figure 5 shows the results of perceptible and acceptable ranges in five conditions of intensity of illuminanace. The perceptible limitation of color reproduction range reduction was not influenced by the intensity of illuminance. The perceptible limitation regardless of the intensity of external luminous is about 78%. However, the acceptable limitation results rise as the intensity of external luminance was increased. The acceptable limitation is 54%, 56% and 61% under different illumination conditions: 400lx, 1000~1500 lx, 2000~4000 lx. Table 3 shows a specific color reproduction range value of JND and JAD. JND of color gamut reduction in transparent LCD is not affected by the color temperature and intensity of external light source. On the other hand, JAD showed a difference value based on the illuminance behind transparent LCD. Through visual assessments, JND/JAD of color gamut reduction of transparent LCD and sensitivity of illuminance was confirmed. Illuminance can contribute to the quantity of transmitted light that is determined transmittance of display. Therefore, Color reproduction range and the transmittance were confirmed to be an important factor in designing transparent LCD.

Table 3. Perceptible and acceptable ranges of color gamut reduction in various intensity of illuminanace(5000K).

intensity of External Luminous	400lx	1000lx	1500lx	2000lx	4000lx
Limit of perception	76%				
Limit of acceptance	54%	57%		62%	

Conclusion

Researches of image quality for transparent LCD have not been done actively. In this respect, the results of this paper have novelty, and these results can help to select luminous sources and images for application of transparent LCD. This paper also can contribute to research for image quality improvement of transparent display. Furthermore, it can help to determine the direction of the transparent display development for manufacturers. Especially, the results of this study can be used cognitive specification for developing inexpensive type transparent LCD.

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