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Image Quality Comparison between LCD and OLED Display

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Abstract

The image qualities of LCD and OLED monitors set to their own default settings were compared using forced-choice experiment method. Both displays' peak white luminance was around 1,000 cd/m2 and color gamut setting was fixed as DCI-P3 for LCD while OLED's gamut was set as DCI-P3 or BT.2020. The twelve image quality evaluation keywords were collected through the focus group Interview and eleven HDR video clips were selected as test stimuli. During the experiment, the test video was shown on two displays placed side-by-side and thirteen naïve participants were asked to select the display having the better image quality. The experimental results showed that OLED has higher image quality than LCD does because of higher colorfulness in general. Black luminance level affected the image quality for the dark images but the images having large bright area, colorfulness affected the overall image quality. This result shows that not display technology but the color characteristics affects the image quality.

Introduction

The panels of displays that are currently in use are largely liquid crystal display (LCD) and organic light-emitting diode (OLED) display. Each panel has different technologies to express images [1]. Therefore, LCD and OLED display the colors on the screen resulting in different color and image characteristics. Most notably, OLED has lower black luminance than LCD because of the backlight. Such technology difference may affect the image quality. However, most previous studies on image quality are conducted using a single display [2][3]. There are only a few studies on how the image quality differences between LCD and OLED are perceived by naïve participants [4].

In this study, the attributes that influence the image quality were investigated by direct comparison between LCD and OLED without any color management between them. For the comparison experiment, the image quality evaluation keywords and test images were selected based on the focus group interviews followed by the forced-choice experiment with naive participants.

Display Setting

LCD and OLED monitors were used for this study. The LCD display was ASUS ROG SWIFT PG27UQ and OLED display was SONY BVM-X300. The size of each display was 27-inch and 30-inch. The maximum luminance was 1128cd/m^2 (LCD) and 954cd/m^2 (OLED). The color gamut followed the display's default settings. LCD used DCI-P3 color gamut and OLED used DCI-P3 and BT.2020 settings. The measured color gamut according to the setting in Figure1 showed that both color gamut of OLED DCI-P3 and BT.2020 were slightly larger than DCI-P3 gamut. The color gamut of LCD DCI-P3 setting was close to sRGB.

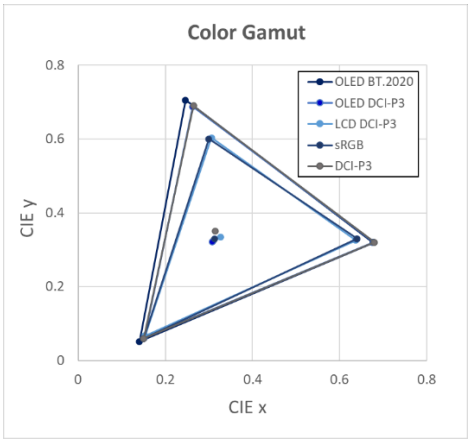

Figure 1 *The measurement color gamut of LCD (DCI-P3) and OLED (DCI-P3 & BT.2020)*

Focus Group Interview

A focus group interview was conducted to select the test images and image quality keywords which can show the image quality differences between LCD and OLED. Three women in their 20s and 30s participated in the interview and were asked to describe the image quality difference between the two displays freely. Various HDR videos were used as the stimuli for interviews. LCD (DCI-P3) was compared with OLED (DCI-P3) followed by OLED (BT.2020). Two displays were placed side by side under the ambient lighting condition. The illuminance was 21.3 lux with 2652K. The position of the participants was not limited.

During the interview, 322 adjectives were collected. The adjectives were categorized into twelve keywords. The keywords were vividness, brightness, objective-brightness, contrast, highlight, 3D effect, detail, sharpness, movement, realistic, and naturalness. Those keywords were used to generate the questionnaire using the terms helping the participant's understanding. For example, the 'contrast' question was expressed as 'significant difference between the bright and dark area'. Table 1 shows the keywords and questions. The focus group interview and the experiment were conducted in Korean.

Table 1 *Selected keyword and created questions*

Keyword	Question (Which display looks ~~er than?)
Vividness	Which display looks more vivid and deeper?
Brightness	Which display looks brighter overall?
Object Brightness	Which object in frame looks brighter? (designated object)
Contrast	Which display has a more significant difference between the bright and dark areas?
Highlight	Which display looks more shining in highlighted area?
3D Effect	Which display looks more three-dimensional?
Detail	Which display shows the finer details better?
Sharpness	Which display shows the boundaries of objects more clearly?
Movement	Which display feels the movement better?
Realistic	Which display feels more realistic like a real scene?
Naturalness	Which display looks more natural? (Skin color, sky)
Overall Quality	Which display looks better?

Image Quality Comparison Experiment

Setting

The experiment was conducted under room lighting conditions. The illuminant setting was 35.6lx and 6500K. Two displays were placed side-by-side and the bezels of the displays were covered with gray papers. Therefore, the participants didn't know which was LCD or OLED. The same HDR videos were played on the displays simultaneously. The distance between displays and participants was 1m. Figure 2 shows the experimental condition.

There were two sessions in the experiment. LCD (DCI-P3) was compared with OLED (DCI-P3) in session 1 and LCD (DCI-P3) was compared with OLED (BT.2020) in session 2.

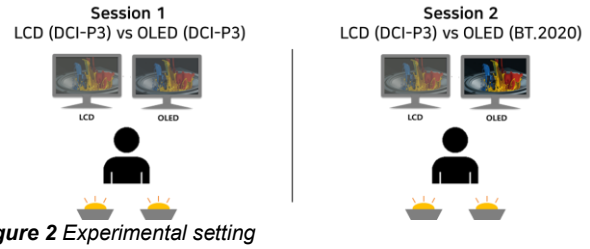

Figure 2 *Experimental setting*

Stimulus

Eleven HDR videos were used for the experiment, and twenty-two scenes were chosen from eleven videos. The HDR videos were found in YouTube. Scenes in videos that the participants noticed the quality differences frequently during focus group interview were selected as the test scenes. 2 or 3 questions were asked for each test scene. For example, in the case of Music 2 containing very colorful colors, vividness, and naturalness, were asked.

Methods

Before starting the experiment, participants adapted to the surrounding condition for 2 minutes. The HDR video was shown on both displays simultaneously. When the test scene appeared, the video was stopped and the questions were asked. Participants selected to LCD or OLED according to questions. After the video ends, the overall quality was asked. Then next HDR video was displayed in random order.

Participants

A total of 13 naïve people participates in this experiment. All the participants have a normal color vision and they were all in the twenties.

Experimental Result

Data Analysis Method

The number of responses evaluated that OLED looks better for each test scene was counted. Then, the proportion was calculated and converted to z-score. If z-score has a positive value, it means that the number of participants who answered that the OLED looks better than LCD was higher, and also if the number of participants who answered that the LCD looks better than OLED was higher, the z-score has a negative value. If all the participants choose an identical display, the z-score is expressed as 1.5*.

Overall Result

Figure 4 is a graph showing the z-scores of each keyword and test scene and Table 2 summarizes the average z-score for each keyword.

At first it is notable that on average, people answered that the OLED looks better than the LCD though there are contents dependency. When OLED had a wider gamut in session 2, z-score of OLED was increased.

For further analysis, the physical measurements and evaluation results were compared, and it was found that the image quality

evaluation was affected not by the type of display but by the color characteristics of the displays.

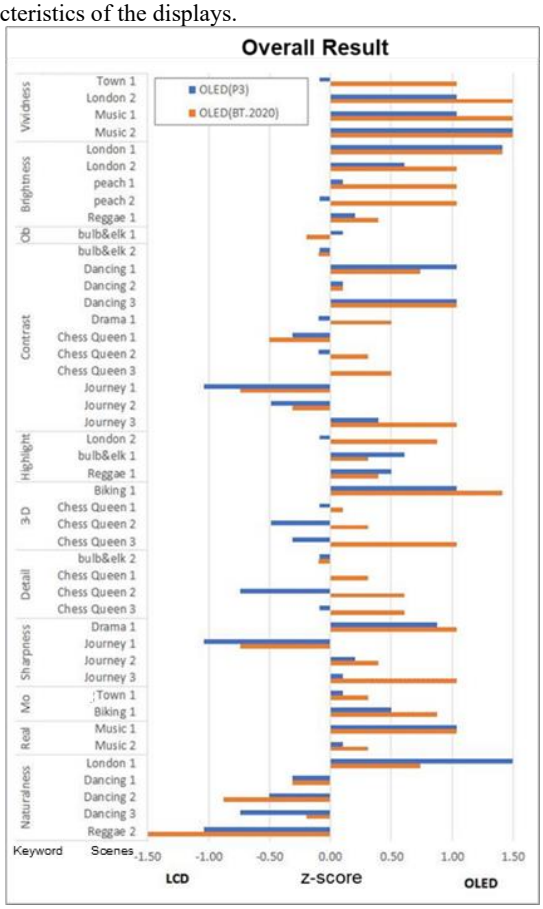

Figure 3 *Overall results*

Table 2 *Averaged z-score of each keyword*

z-score	LCD (DCI-P3) vs. OLED (DCI-P3)	LCD (DCI-P3) vs. OLED (BT.2020)
Vividness	0.87	1.39
Brightness	0.45	0.98
Object brightness	0.10	-0.20
Contrast	0.04	0.23
Highlight	0.34	0.53
3-D effect	0.04	0.72
Detail	-0.23	0.36
Sharpness	0.04	0.43
Movement	0.30	0.60
Realistic	0.57	0.68
Naturalness	-0.22	-0.43
Average	0.21	0.48
Overall Quality	0.15	0.73

Vividness vs Naturalness : Effect of Colorfulness

In the case of the vividness, OLED had better evaluation results regardless of the OLED color gamut setting. Color measurement results found that even though the LCD and OLED were set to the same color gamut, the actual colorfulness of the OLED was higher.

Table 3 *Colorfulness and vividness (z-score) in music 1*

Colorfulness(M)	Paint Red	Paint Yellow	Paint Blue	Vividness (z-score)
LCD	97.81	78.58	90.58	
OLED (DCI-P3)	108.06	91.36	96.95	1.04
OLED (BT.2020)	139.94	94.8	104.17	1.50

For example, in the case of Music 1, most participants selected OLED in the vividness evaluation. Table 3 shows the calculated colorfulness M in CIECAM02. OLED was evaluated to be more vivid because the colorfulness of the OLED was higher. On the other hand, the luminance of the background color is 0.9 cd/m^2 for the LCD and 1.3 cd/m^2 for the OLED, affect the image quality evaluation.

Unlike the vividness, the preference for OLED was lowered than LCD in naturalness. Especially skin colors became excessively saturated in the wider color gamut. In Dancing 2 and Reggae 2 scenes both showing the actresses, z-score was -1.04, -0.5 in session 1 and -0.5, -0.88 in session 2.

Overall Brightness : Helmholtz-Kolrausch Effect

London1 scene contains large bright and vivid area. When asked to select a display that looks brighter overall, OLED was preferred. As shown in Table 4, LCD had the highest luminance in the main areas of the scene compared in both the OLED (DCI-P3) and OLED (BT.2020) while the colorfulness was higher on OLED than LCDs It means that not the luminance but the colorfulness affected the overall brightness of the scene.

On the other hand, in the Peach 1 image with a wide bright and desaturated area, there was little difference in perceived brightness when the two displays had the same color gamut. However, the z-score value increased in the OLED (BT.2020) setting from 0.10 to 1.04. This means that when the participants evaluated the overall brightness of the Peach1 image on OLED (BT.2020), they were affected by the colorfulness of the vivid object having small area. The perceived brightness of the entire image increases as the saturation of some areas increased.

In conclusion, in the case of overall brightness, if the luminance is similar, the overall image looks brighter as the colorfulness increases, which corresponds to the Helmholtz–Kohlrausch effect.

Table 4 *Luminance of main area*

Luminance (Y)	London 1	Peach 1
LCD	173.52	173.55
OLED (DCI-P3)	166.1	158.21
OLED (BT.2020)	163.96	157.24

Table 5 *z-score of brightness in London 1 and Peach 1*

Brightness (z-score)	London 1	Peach 1
Session 1	1.41	0.10
Session 2	1.41	1.04

The Effect of Luminance

Contrast

In the case of perceived contrast, evaluation results were similar with the physical white-black luminance ratio. That is, the higher the luminance ratio, the higher the perceived contrast. As an example, Chess Queen1 image shows higher luminance contrast on LCD than OLED and the z-score was -0.31 in session 1 and -0.5 in session 2.

However, when the OLED color gamut was changed to BT.2020, the 3D effect and Detail slightly improved i.e. a higher z-score in OLED. This is because the color of the background, and the gold ornaments becomes standing out, making it more three-dimensional showing more details.

Table 6 *Ratio of luminance in Chess Queen 1 scene*

Chess Queen 1	Ratio of luminance (Contrast)
LCD	104.5
OLED(DCI-P3)	95.5
OLED(BT.2020)	96.4

Table 7 *z-score of Chess Queen 1 scene*

z-score	Perceived contrast	3D effect	Detail
Session 1	-0.31	-0.09	0.10
Session 2	-0.50	0.00	0.31

Dark Area

From Journey 1 scene to Journey 3 scene, the black area is getting smaller. In Journey 1, perceived contrast and sharpness of the LCD, which had lower black luminance, was evaluated to be better regardless of the color gamut of the OLED. However, for Journey 3, OLED's image quality was much better than LCD especially under BT.2020 setting.

This means that as the black area gets smaller, the contrast and sharpness are affected by the colorfulness of the bright area.

Table 8 *Luminance of black area in Journey 1 scene*

Journey 1,2,3	Luminance of black area (Y)
LCD	0.29
OLED(DCI-P3)	0.41
OLED(BT.2020)	0.41

Table 9 *z-score of perceived contrast and sharpness in each scene*

z-score		Perceived Contrast	Sharpness
Journey 1	Session 1	-1.04	-1.04
	Session 2	-0.74	-0.74
Journey 2	Session 1	-0.49	0.2
	Session 2	-0.31	0.39
Journey 3	Session 1	0.39	0.1
	Session 2	1.04	1.04

Conclusion

In this study, the image quality was compared by a direct comparison between LCD and OLED. For evaluating the image quality from the consumer's point of view, the keywords which were used for image quality comparison were selected from focus group interview. The image quality comparison experiment was conducted with 12 keywords questions. Participants were asked that which displays look better about questions. A total of 22 scenes was evaluated in the experiment.

As a result, it was investigated that the image quality evaluation was affected by the color characteristics of the display, instead of the types of panels. Higher contrast and larger color gamut was preferred in general.

Black luminance level affected the image quality of the images having large dark area. The images having large bright area, colorfulness affected not only the vividness but also the overall brightness as well confirming the Helmholtz-Kolrausch effect.

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Author Biography

Garam Seong received her BS in electrical engineering from the Ulsan National Institute of Science and Technology UNIST (2018) and her MS in human factor engineering from the UNIST (2020). She is PhD students in UNIST. Her work has focused on the image quality of the display.

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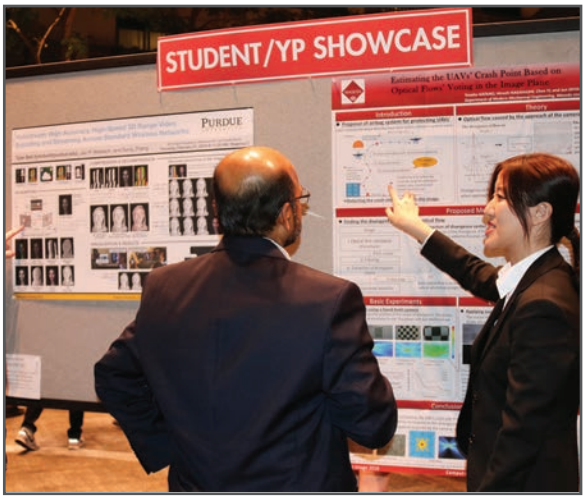

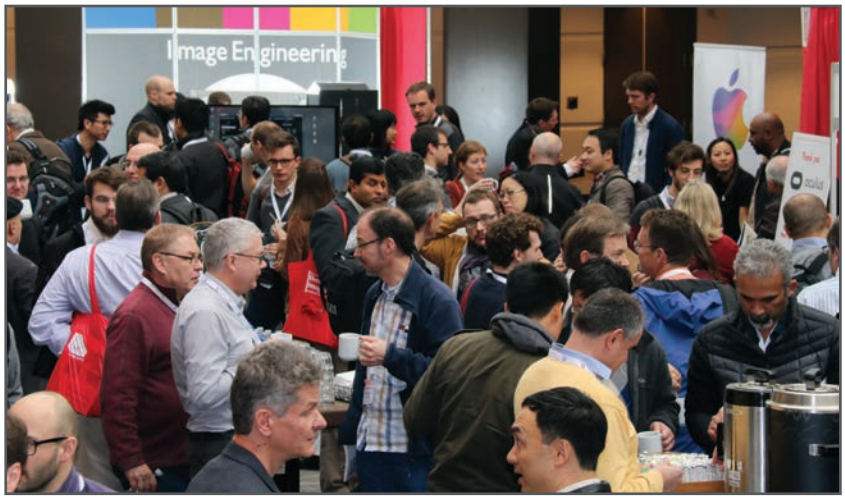

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