A Novel Display Performance Index for Picture Quality Evaluation and Content Color Reproduction under Ambient Viewing Condition

Mincheol Kim*, Sungjin Kim*, Yongjune Kim*, Dongwoo Kang *,
JoonYoung Yang*, SooYoung Yoon*
***LG Display, Seoul, Republic of Korea**

Abstract

Displays are predominantly used in bright rooms than in dark rooms. Therefore, the evaluation of picture quality in real-world environments requires consideration of bright room conditions. In Addition, the reflective properties of displays and content are key factors in bright room conditions. By considering these characteristics, this paper proposes an evaluation method to assess display image quality in real-world environments.

Author Keywords

Image quality evaluation; Ambient Viewing Environment; Display Performance; Content Color Reproduction.

1. Introduction

Recently, with the growth of the OTT market, a significant amount of High Dynamic Range (HDR) content has been distributed through these platforms. This development has made high-quality HDR content more accessible to consumers via streaming. HDR content require higher display specifications because they have a wide luminance range and a wide gamut of BT.2020 as a standard [1]. Among various display technologies, OLED displays are considered one of the best options for displaying HDR content. OLED displays are self-emission displays that can express black close to 0 cd/m^2 and offer a high dynamic range and excellent color reproducibility. There are various metrics to evaluate the optical characteristics of OLED displays. Color volume is one of the image quality indices used to compare these properties.

Color volume is an image quality index that evaluates the color gamut according to luminance changes as a three-dimensional volume. The color volume of Standard Dynamic Range (SDR) is evaluated based on the international standard of IDMS [2], but There is no standardized evaluation criterion for HDR color volume yet. Therefore, it is usually calculated based on the maximum color volume of the display. Color volume is evaluated through the measurement of luminance and color performance of display in dark room, but this evaluation method may have certain limitations in accurately representing picture quality under real-world conditions. To accurately represent the real-world viewing condition, it is essential to consider not only the size of the volume but also the illumination of viewing environment and content characteristics.

In general, displays are typically viewed in bright environments rather than in dark room. It is widely recognized that most of users view displays under ambient lighting condition(office/home) ranging from 50 lux to 500 lux [2][3]. Therefore, to evaluate the picture quality based on a real-world viewing environment, it is necessary to consider not only a dark room but also a bright room condition.

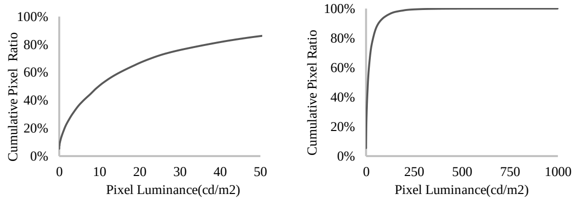
In a bright room condition, the reflective properties of the display have a significant impact on the luminance and color coordinates in the low-gray area. Therefore, A display with high reflectance is unable to properly reproduce low-luminance areas in a bright environment. In HDR content, the accurate representation of low luminance is particularly important. Because it is essential for HDR content to accurately represent the creator's intention, and a significant amount of content information is distributed in low-luminance areas [4][5].

In this paper, we proposed an index to evaluate display image quality in real-world condition. In Section 2, the importance of reflective properties is highlighted through the analysis of HDR content. In Section 3, specific evaluation process of the proposed method is described. In Section 4, evaluation results of the proposed method are discussed. Finally, Section 5 concludes the paper.

2. Characteristics of HDR Content

Based on the IEC Broadcast standard video, the characteristics of typical HDR videos were analyzed. IEC Broadcast Test Video (IEC 62087-2:2021 Test Video) is a representative HDR standard video used for power consumption evaluation and peak luminance ratio determination [6]. This video is a new evaluation video developed by the European program of Collaborative Labeling and Appliance Standards Program (CLASP). A revised video has been developed to provide image quality characteristics similar to those of the existing evaluation video (IEC 620487:2015 Test Video). Furthermore, the number of content cuts has been reduced to better represent general program content [7]. The video clips include various custom-filmed clips such as street scenes, sports, advertisements, staged television dramas, and news talk-show clips. Due to these characteristics, this video can be considered representative of general HDR content characteristics. It is also used to evaluate the power consumption and luminance performance of TV sets in the European power consumption standard The Energy-related Products Directive (ErP) and ANSI/CTA-2037-D.

IEC Broadcast HDR video was mastered based on HDR10 and 1000cd/m^2. Figure 1 illustrates the luminance distribution of each pixel in the IEC Broadcast HDR video.



(a) 0~50cd/m^2 (b) 0~1000cd/m^2

Figure 1. Luminance analysis of the IEC Broadcast video

The analysis results graph shows that most of the pixel data is distributed in the low luminance area. More than 85% of the data is below 50cd/m^2, and 13% is below 0.5cd/m^2. Therefore, the representation of low luminance is crucial for accurately reproducing content on a display, and the reflective properties of display are also an important factor. This occurs because most viewers watch displays in bright environment. Under such

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conditions, black luminance increases due to display reflectance. Even if black increases by only 0.5cd/m^2 due to reflection and ambient illuminance, 13% of the pixel data becomes difficult to accurately reproduce. Therefore, it is important to consider the bright environment and reflective properties of a display when evaluating its performance. Additionally, a new evaluation index is required to quantify this phenomenon.

3. Content Coverage Analysis Method

The proposed method is calculated based on the overlap ratio between the color volume of the display and the pixel data of the content. Additionally, to account for real-world viewing conditions, the reflective properties of display are incorporated into the calculations. This ratio is defined as the display's content reproduction capability (Content Coverage). This section explains the detailed process of the proposed Content Coverage analysis method.

First, the characteristics and measurement methods of the display used for evaluation are described. Second, the selected HDR content for analysis are introduced, and the analysis method of the content is explained. Finally, a method to evaluate the display's content reproduction capability by integrating the analyzed HDR content, display color volume, and viewing condition is introduced.

Optical and reflective properties of Display: Three types of 65inch OLED TVs with different luminance, color gamut, and reflection characteristics were used for this evaluation. To consider the reflective properties of display, the black level of the display was measured in a bright environment. The measurement method was based on the Ring-light reflection in the Reflection and Transmission Measurements of IDMS [2]. The illuminance of the viewing environment according to the intensity of the ring-light was calculated using a white reflectance standard with a known reflectance, as shown in Equation 1.

$$E = \pi L_{std} / \rho_{std} \qquad (1)$$

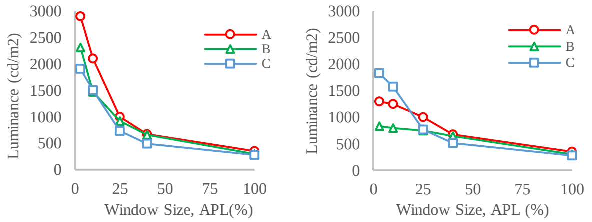
E: illuminance
L_{std}: luminance of the white reflectance standard
ρ_{std}: reflectance of the white reflectance standard

The illuminance was configured based on four viewing environments: dark room, 50 lux, 200 lux, and 500 lux. The reflective luminance of display for each ambient illuminance was measured with a Konica Minolta CS-2000 Spectro-meter and derived as CIE 1931 XYZ values.

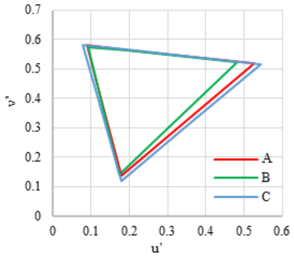
The results of measuring the reflective properties of each display are illustrated in Table 1, and the luminance and gamut of the displays are shown in Figure 2. According to the measurement results, Display A has excellent reflection, but its color gamut is slightly smaller than that of Display C. On the other hand, Display C has the largest Color Gamut, but its reflected luminance is relatively high. Display B has moderate reflection performance and the smallest color gamut. Additionally, the luminance measurement results in Figure 2 illustrates that Display C has higher color luminance in low Average Picture Level (APL) regions compared to Display A and B, but lower white luminance and color luminance in regions below 25% APL. By comparing these displays with different characteristics based on proposed method, the impact of each display evaluation factor can be identified.

Table 1. Display reflection characteristics.

Display	Reflection [%]				Black Luminance [cd/m2]		
	Total	Specular	Haze	Lambertian	50lx	200lx	500lx
A	0.66	0.54	0.04	0.07	0.015	0.066	0.161
B	0.9	0.37	0.16	0.36	0.077	0.348	0.86
C	2.06	0.16	1.23	0.65	0.218	0.589	1.453



(a) White Pattern (b) Sum of R, G, B



(c) Color Gamut (CIE 1976)

Figure 2. Measurement results for Luminance and Gamut

HDR Color Volume Measurement: Most OLED displays have different luminance characteristics depending on the APL of the image. To evaluate the content reproduction quality by reflecting these characteristics, the color volume of the display according to the APL is required. To measure the color volume according to the APL, a new measurement pattern was created by modifying the CAPL-25 pattern used in the SDR color volume measurement standard [2]. The size of each window area of CAPL-25 was adjusted to the same ratio for each APL. The pattern was created as an HDR signal using the Astro Video Signal Generator (VG-876) and measured using the Konica Minolta CA-410. Since it is practically impossible to measure the color volume of all APLs, 10 APLs at 10% intervals and 3% APLs were added to measure a total of 11 APL representative values, and the interval between each APL is assumed to be the same APL measurement value as a range.

HDR Content Selection and Analysis: HDR content was analyzed not only for the standard IEC Broadcast evaluation video, but also for various types of commonly consumed content. Common content was composed to include various genres and scenes. The common content is broadly categorized into four genres for analysis: movies/dramas, promotional videos, games, and landscape videos. The total length of content used in the analysis was 1090 minutes, consisting of at least 80 different video clips per genre. The composition ratio by content genre is shown in Figure 3. Movies/dramas typically feature relatively darker scenes compared to other genres, but they also include bright and colorful videos such as animations. Promotional videos refer to videos produced by TV or display companies for new product promotions. These videos are composed of scenes that are bright and colorful to maximize the performance of the products, requiring a wide gamut and high brightness. For games, we selected content that is mainly played on console game devices, and most have characteristics similar to movies/dramas. Lastly, landscape videos represent scenes that can be seen in everyday life. These videos were filmed and mastered by the author in various locations, including Juju Island (South Korea), San Francisco and Los Angeles (USA), and Tokyo (Japan). Landscape videos were shot using the Sony Fx3 cinema camera in 4K, 59.94p, with S-log3 gamma & S-Gamut3.Cine and were HDR mastered based on SMPTE ST2084 and BT.2020.

The selected HDR content was decoded using FFMPEG decoder. The input video signal was converted based on the metadata of the video packets, and the signal of the video packets compressed in YUV was decoded to 16-bit RGB code values for analysis. The content analyzes each frame and pixel, storing not only the R, G, B code values of each pixel but also the APL of each frame. This is because the APL of the video is necessary to reflect cases where the color volume of the display changes according to the APL. Since most HDR video is mastered SMTPE ST2084 EOTF and BT.2020 Gamut, we chose to store R, G, B code values instead of color coordinates and luminance information to reduce the number of data cases. If there are cases with the same APL and code values, the count value is increased to determine the frequency of that information. The APL, R, G, B, and count information is saved as a database for each video. The 100% reference for the APL of each frame was calculated based on DCI-P3 1,000cd/m^2. This result was classified according to the 11 APL criteria used for measuring display color volume.

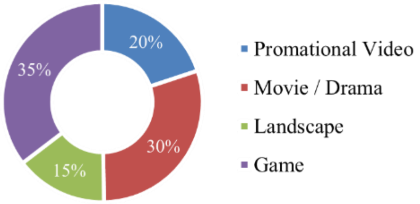


Figure 3. The proportion of analyzed content by genre

Figure 4. Example of a landscape video scene

Calculating Content Coverage: Based on the measurement results of the display and the analyzed content information, the Content Coverage of the display is finally evaluated. Figure 5 illustrates the entire process of evaluating the Content Coverage. First, the content database used for the analysis is sequentially loaded. Second, the measurement data for display color volume, corresponding to the APL of each database, is loaded. Changes in black color coordinates according to illuminance are added to the display color volume data to reflect the impact of real-world viewing conditions. The R, G, B code value of the content database and display color volume measurement data are transformed into a color space for Content Coverage calculation. In the analysis of this paper, the ICtCp color space proposed by Dolby was used [8]. ICtCp is a color space developed for the measurement HDR and Wide Color Gamut analysis. In addition, ICtCp is a color space for HDR and Wide Color Gamut specified in the ITU-R BT.2100 standard [1] and is also utilized by various display evaluation organizations.

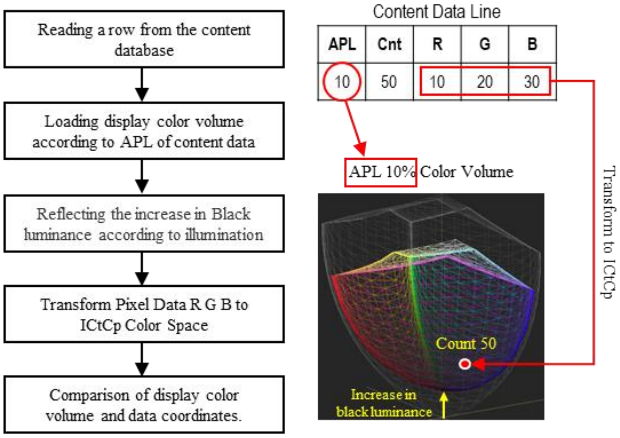


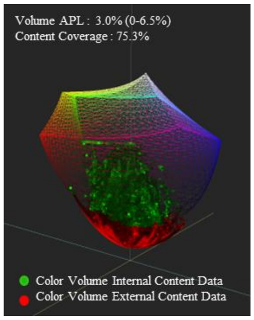
Figure 5. Systematic diagram for calculating Content Coverage

Finally, it is determined whether the content information is inside or outside the color volume of the display. This process is performed on the entire database and is expressed as a ratio as shown in Equation 2. This ratio is defined as the Content Coverage value of the corresponding content and display.

$$\mathit{Content\ Coverage}(\%) = \frac{\text{the number of data within color volume}}{\text{total number of pixels in the content}} * 100 \qquad (2)$$

Figure 6 illustrates an example of the evaluation results of Content Coverage. The calculation results include not only the overall Contents Coverage result but also the analysis results for each APL interval. Additionally, 3D visualization feature enables the analysis of content information by visualizing whether it lies inside or outside the display's color volume.

APL Range	Data Proportion	Coverage
0 - 6.5	75.40%	75.30%
6.5 - 15	21.16%	95.98%
15 - 25	3.14%	96.40%
25 - 35	0.30%	88.97%
35 - 45	0.00%	100.00%
45 - 55	0.00%	100.00%
55 - 65	0.00%	100.00%
65 - 75	0.00%	100.00%
75 - 85	0.00%	100.00%
85 - 95	0.00%	100.00%
95 - 100	0.00%	100.00%
Total	589690879	80.38%



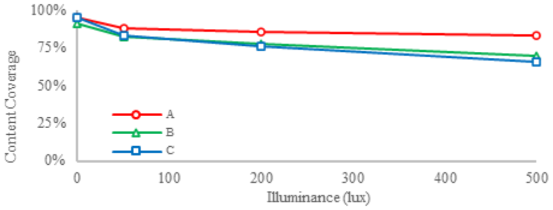
(a) Calculation Result (b) 3D visualization

Figure 6. Analysis Example of Content Coverage

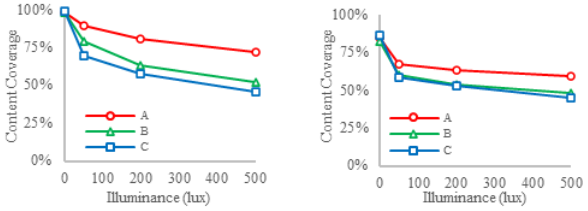
4. Content coverage Evaluation Results

Figure 7 shows the results of the comprehensive evaluation of Content Coverage by genre. The evaluation results show similar trends overall, although there are some characteristics by content genre. In the darkroom, the Content Coverage of all displays is similar, and most of them are close to 100%.

This trend in values results from the fact that most colors encountered in daily life are contained within DCI-P3[5] and most HDR content is mastered based on 1,000 cd/m2 and DCI-P3[9][10]. In the case of promotional videos and landscape videos, some scenes with high brightness and exceeding the DCI-P3 are included, so the Content Coverage in the darkroom is somewhat lower than in other genres.

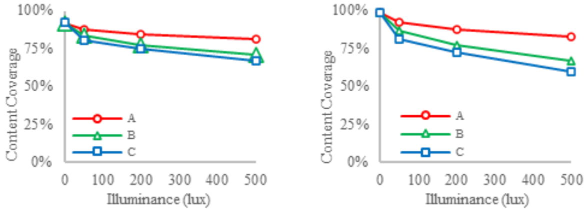


(a) IEC Broadcast Standard Video



(b) Movie & Drama

(C) Promotional Video



(d) Landscape

(e) Game

Figure 7. The analysis results of the proposed method

In a bright room, even at an illuminance level as low as50 lux, differences become noticeable. This is because low-luminance areas constitute a significant portion of most content. Promotional videos, in particular, often feature scenes with objects against dark backgrounds. As a result, Content Coverage changes significantly when conditions shift from a darkroom to a bright room.

In the case of color volume evaluated in a darkroom, Display C with the largest color gamut may be superior, but Display A demonstrates superior results in Content Coverage. Rather, Display C shows the worst evaluation results in Content Coverage in most cases. This result can be interpreted as meaning that it is difficult to evaluate the content reproduction image quality of a display with only the size of color volume. Furthermore, from the perspective of an actual user, the extent to which the area of content data can be covered under real-world viewing condition is a more meaningful evaluation result than the size of color volume. In that sense, the Content Coverage evaluation method is considered a meaningful image quality evaluation index, and it can be confirmed that the display's reflective performance is also important in maintaining good picture quality in various genres and viewing environments.

5. Conclusion

In this paper, a novel evaluation method was proposed to more accurately evaluate display image quality based on real-world viewing environments. Additionally, the evaluation results were analyzed considering various viewing environments and a wide range of content genres.

In conclusion, in a darkroom condition, nearly 100% Content Coverage was achieved in most cases. However, in a bright room, the Content Coverage results varied across displays. This difference reflects the impact of increased black luminance and reduced color gamut caused by the reflective properties of each display. In the case of Display A, which had excellent reflective performance, Content Coverage was maintained even in a high-illuminance. However, in the case of Display C which had relatively poor reflective properties, there was a significant difference in Content Coverage between the dark rooms and the bright rooms.

Based on these results, it was confirmed that reflective properties of a display are as important as luminance and color gamut in evaluating display quality.

In addition, the increase in black luminance caused by the reflective properties of display negatively impacts contrast, which is crucial for OLED TVs. Based on these results, the proposed Content Coverage is considered a reliable approach for evaluating display quality under real-world conditions.

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