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Effects of Black Luminance Level on Image Quality

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Abstract

The image quality is affected by the black luminance level of the image. This research aimed to investigate how low luminance levels are required to maintain image quality. The psychophysical experiment was carried out in a dark room using OLED display. Total of 6 different black luminance levels (0.003, 0.05, 0.1, 0.2, 0.3, and 1 cd/m^2) were used in the experiment. Total of 20 participants was invited to evaluate the image quality. For the experiment, twelve test images are used and these test images categorized into three groups as dark, medium bright and bright image group by image histogram distribution. Each image is rendered by adjusting six different black luminance levels. Result found that the black level is higher than 0.1 cd/m^2, the preference for the image is decreased. The best performance is achieved when the black level is 0.003 cd/m^2, but there is no big difference from 0.1 cd/m^2. The final result shows that a change in black level between about 0.003 cd/m^2 and 0.1 cd/m^2 does not significantly affect image quality.

Introduction

Recently, High Dynamic Range (HDR) is a most important issue in image devices industry. When displaying image content with Standard Dynamic Range (SDR), shadows tend to clump or bright areas become white, while HDR provides a more natural representation of dark or bright areas. HDR can express shadow and light more closely to what the human eye perceives. There are some standards for HDR video. The International Telecommunication Union – Radio communication sector (ITU-R) BT.2100 recommends image parameter values for HDR television including minimum luminance (black level) and peak luminance of HDR display. [1] In this Recommendation, minimum luminance and peak luminance are $\leq$0.005 cd/m^2 and $\geq$1000 cd/m^2, respectively. Also, HDR video standard HDR 10+ [2] recommends luminance in the range of 0.005 or less to 1000 cd/m^2 or more. These recommendations are disadvantageous for Liquid crystal displays (LCD) in which less light is leaked by the backlight even when digital input signals are 0.

The blackness of the image greatly affects the image quality. An image on the darker background appears brighter than an image on the lighter background. [3] LCD manufacturers try to reproduce the black luminance level as low as possible. Rafal K. M. et.al. found a pure black (the lowest luminance perceptually measured) as low as 0.0044cd/m^2 for dark surround. [4] If pure black cannot be reproduced, it is necessary to study how low brightness levels affect image quality. Some of the studies [5, 6] evaluated the viewer's preference for the black and white luminance levels of an image using a prototype HDR display. 50% of naive and technical viewers satisfied black levels of 0.1 and 0.04 cd/m^2, respectively. This results show displays capable of a luminance range is between 0.1 and 650cd/m^2.

In this study, we examined the effect of black luminance levels on image quality using various images. These images were rendered to have six different black luminance levels (0.003, 0.05, 0.1, 0.2, 0.3, 1 and 1 cd/m^2).

Psychophysical Experiments

Experimental Set-Up

In this experiment, the OLED TV was used to reproduce the deepest black (0.003 cd/m^2). The physical size and resolution of this OLED display were 65-inch and 3840×2160, respectively, and it was a curved type of display.

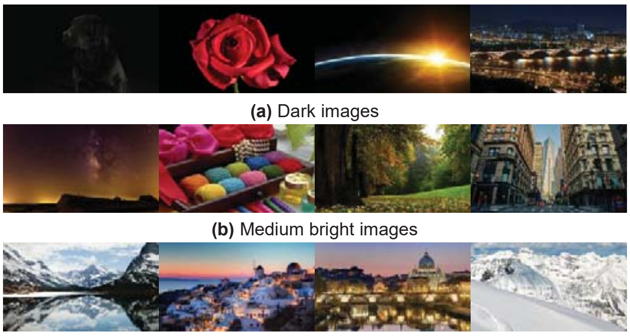
The test pattern was designed as shown in Fig. 1. Two test images with the different black luminance levels were placed on a black background. These two images were in the center area of the display to consider that the display used in this experiment was a curved type. The distance between the two images was 50 pixels. Both images were visible at the same time.

The tri-stimulus values (XYZ) of display characteristics and testing black luminance level were measured using a Minolta spectroradiometer CS-2000 with measuring angle of 1˚. The maximum luminance and the minimum luminance were 650 cd/m^2 and 0.003 cd/m^2 (minimum luminance of CS-2000), respectively, and the color gamut was set to DCI-P3.

Figure 1 *Test pattern configuration*

Test image selection

The ‘darkness’ of the image i.e. the proportion of dark pixels in an image was considered to selected test images. The digital RGB value of each pixel for the image was estimated as XYZ tri-stimulus value considering the characteristics of the TV used in this experiment. In this study, the pixels having the luminance (Y) lower than 1 cd/m^2 are considered as dark pixels. At the black setting level, the highest level is 1 cd/m^2. Accordingly, the pixel having lower luminance than 1 cd/m^2 for the original image was determined as dark pixels. Total of 12 test images was used in this experiment as shown in Fig. 2. The test images were divided into 3 groups – Dark, Medium Bright, and Bright groups. Table 1 indicates the ratio of darkness and average luminance. If more than 60% of the pixels of the image are dark pixels, that image is classified as a dark image group. (image 1 to 4). The images with the percentage of the dark pixels between 20 % and 40 % were classified as a medium bright image (image 5 to 8). And the percentage (less than 20 %) of the dark pixels was classified as a bright image (image 9 to 12). In addition, the images were composed of various colors ranging from a colorful image to a low chroma image. The size of all images was 1280 × 720 pixels.



(a) Dark images

(b) Medium bright images

(c) Bright images

***Figure 2** Test images*

Test Image Manipulation

Total of 6 different black luminance levels was used to simulate the minimum luminance of the display. Table 2 indicates the luminance and CIELAB lightness (L*) of black luminance levels. The maximum luminance of display (650 cd/m^2) was set to as a reference white. 0.05 cd/m^2 was sufficiently distinguishable from 0.003 cd/m^2. 0.1 cd/m^2 and 0.3 cd/m^2 were assumed to be a black level of LCD TV (HDR) and normal LCD monitor (SDR), respectively.

To adjust the black level, the RGB input signal of the image was converted to the tri-stimulus value XYZ considering the characteristics of the display. Each black level was added to all of the pixel values. When a black level was added to an image, the color value of the mid-gray might be changed but it was not large enough to affect the image quality. The color gamut also did not change significantly. In total, 72 images were prepared for this experiment (12 test images × 6 black luminance levels).

Table 2. The black Luminance levels and CIELAB L*

Black Levels	Y (cd/m^2)	CIELAB L*
1	0.003	0.0
2	0.05	0.1
3	0.1	0.2
4	0.2	0.5
5	0.3	0.7
6	1	2.5

Participants

Twenty participants (11 females and 9 males) with normal color vision participated in the experiment. They were the student at the Ulsan National Institute Science Technology, with ages ranging from 20 to 30 years and naïve for the image quality evaluation. All of them had not a basic knowledge of color science. Therefore they received basic training before the experiment.

Experimental Procedure

In order to conduct the experiment, image preference was tested to evaluate image quality using the paired comparison method. Figure 3 shows the experimental procedure. Before performing the experiments, each observer had a training session to understand the concepts of these experiments. For the concept of image preference, the observers decided to select the preferred image considering the case of purchasing a TV. As a first, they sat in front of the display and adapted to the black screen about three minutes in a dark room. When they were adapted for a dark room condition, a test pattern was displayed.

Table 1 The darkness and the average luminance of the test image

Image Category	Test Images	The percentage (%) of the dark pixel (Y<1 cd/m^2)	average luminance (cd/m^2)
Dark	image 1	84.3	1.08
	image 2	61.09	26.17
	image 3	40.54	63.96
	image 4	39.68	39.68
Medium bright	image 5	14.5	31.22
	image 6	14.4	62.54
	image 7	11.6	76.01
	image 8	10.1	93.46
Bright	image 9	4.4	220.86
	image 10	4.1	143.39
	image 11	0.4	130.32
	image 12	0.3	377.40

For each test image, two of the rendered images were randomly selected as a pair set and displayed side by side on the display as shown in Fig. 1. The participant evaluated the difference between the two rendered images. If there were any differences between the two image, the participant was asked to select the most preferred image using the ‘left’ and ‘right’ arrow keys on the keyboard. Using the forced-choice method, participants had to select one image unconditionally, even if they did not feel any change between the two images.

Each evaluation was given a maximum of 3 seconds. After finished an evaluation, the black screen was displayed again to eliminate after-image for test colors and participants were adapting again. The number of the pair set was 15 (= 6 × (6-1)/2) for one test image. Total 360 evaluations (15 black luminance pair set × 12 test images × 20 participants) were collected. 15 test pair set were randomly displayed. All of the evaluations were conducted in a dark room to reduce the influence of glare reflection by the ambient light source. The viewing angle was about 9° horizontally and 6° vertically at a viewing distance of 1.5 meters.

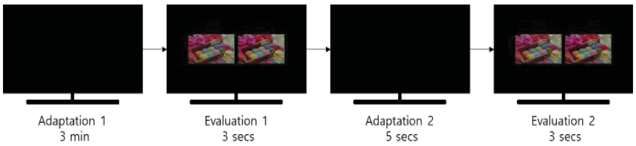


Figure 3 *Experimental procedure*

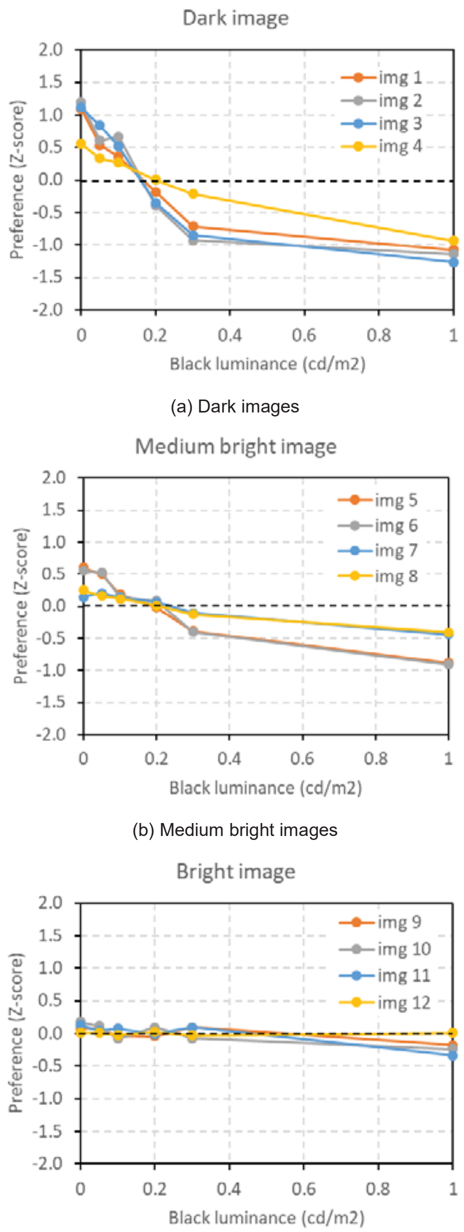
Experimental Results

The experimental results were analyzed by calculating a z-score. A positive score indicates that the image preference is higher than the average score, while a negative score means lower preference. Figure 4 represents the experimental results of each test image group. In these graphs, the x-axis is black luminance level. The y-axis is the image preference in z-scores.

In dark images, image preference decreases sharply as black luminance increases. In an image with a lot of black pixels, the contrast of the image seems to increase with the black level. This has increased the image preference. Image 4 showed no significant difference between 0.003 and 0.1 cd/m^2 even though more than 61% of pixels were distributed in the black region. In fact, the participant perceived a lightness difference between 0.003, 0.05 and 0.1 cd/m^2. However, the difference was not large enough to affect image preference.

Medium bright images have slowly decreased in preference than dark images. The results show image preference is beginning to decline from 0.05 and 0.1 cd/m^2. It means that a change in black level between about 0.003 cd/m^2 and 0.1 cd/m^2 does not significantly affect image quality.

On the other hand, for the bright images, most of the data points are plotted near zero z-score. Image 10 and 11 were not very bright with average luminance values of 143 and 130 cd/m^2, respectively, but the observers could not distinguish the difference between two images because of the small ratio of the black pixel. Furthermore, image 12, which is a snow-covered image, was plotted horizontally at almost zero z-score. It means that there were no preference changes by a black luminance level. That is, the black luminance level does not work on bright images. From the results, also it is notable that the images having a large black area is more affected by the black luminance.



(a) Dark images

(b) Medium bright images

(c) Bright images

Figure 4 *Image preference (z-score) by test images*

Experimental results are shown according to the degree of inclusion of black in the image. Figure 5 shows the average results for all test images. The highest preference is in 0.003 cd/m^2. However, the difference is small compared to 0.05 and 0.1 cd/m^2. Overall, black luminance from 0.003 to 0.1 cd/m^2 does not have a significant effect on image quality.

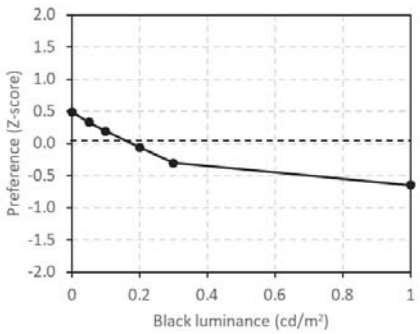


Figure 5 *Image preference (z-score)_average value*

Conclusion

In this research, the effect of low luminance level on image quality was investigated using OLED display in a dark room. Total of 6 black luminance levels (0.003, 0.05, 0.1, 0.2, 0.3, and 1 cd/m^2) were tested in the experiment. Twelve images were selected as a test image. These images were rendered to have different black luminance levels and compared each other using paired comparison methods. The participants were asked to use forced-choice preferences of test images as if they were considering case of purchasing a TV.

The black luminance level between about 0.003 and 0.1 cd/m^2 does not significantly affect image quality. The black level is 0.1 or higher, the preference of the image decreases. The best performance is achieved when the black level is 0.003, but there is no big difference from 0.1 cd/m^2.

In this experiment, the test images were displayed side by side. In this case, the luminance difference may be under perceived. In further research, the experiment on the blackness effect will be carried out by using the temporal method which the image appears in the same position in time. A typical TV viewing environment is when there is an ambient light source. In this case, the perception of black may show different results. Therefore, in future studies, the experiment should be conducted in the ambient light conditions to consider consumer viewing condition.

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