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An Analysis of Effects Provided by High-Gradation Displays Based on Impression Assessments

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Abstract: Recently, even though the use of high-gradation display devices in medical and other specialized fields has become essential, most devices in general field usage are still typically 8 bits luminance level displays. However, since it can be presumed that image quality improves when high-gradation display devices are used, we investigated the results obtained by increasing luminance gradation levels and found that image impressions improved as the number increased. In addition, the results indicated that the impression improvement peaked at just less than 9 bits.

Keywords: High-gradation display, Gradation number, Impressions.

1. INTRODUCTION

Stimulated by recent advances in high-resolution technology, 4K displays (which is a general term for displays with horizontal resolutions of approximately 4,000 pixels) have already entered the market. However, while the spatial resolution of such devices has improved, the gradation number of such devices, which are quantified by their luminance resolution number, has remained static in recent years. In specialized fields where serious quantitative improvements to display quality are in constant demand, such as the medical and color management fields, high-gradation display devices are used (DICOM, 2000). Yet, the luminance gradation level of most general display devices used for presenting content currently remains at just 8 bits. In this study, we began by presuming that image impressions improve with gradation number increases because high-gradation display devices are more capable of reproducing smooth gradation changes. In two related studies (Daly, Kunkel, Sun, Farrell & Crum, 2013; Kusakabe, Kanazawa, Nojiri, Haino & Furuya, 2011) into qualitative assessments using high-gradation display devices, researchers focused on the dynamic range of display devices, not on their luminance gradation levels. Other studies (Seetzen, et al., 2004; Bimber & Iwai, 2008) discussed the necessity of high-gradation display devices based on the just noticeable difference (JND) factor. These studies determined that the optimum gradation number of a display could be found when the luminance-difference between each pixel value is slightly smaller than the JND.

Although, JND is measured under full adaptation to a given stimulus (DICOM, 2000; Wyszecki & Stiles, 2008), in this study we adapt to the maximum luminance in the displayed content using a general display device. In addition, we look at the entire display, and not at individual pixels. Thus, because the visual performance conditions are different from those used in general viewing, it was considered necessary to examine the effects of a high-gradation display based on impression assessments rather than the JND. Therefore, in this study, we examine the impressions provided by high-gradation display devices and the contents that evoke conspicuous impressions.

2. IMPRESSION ASSESSMENTS

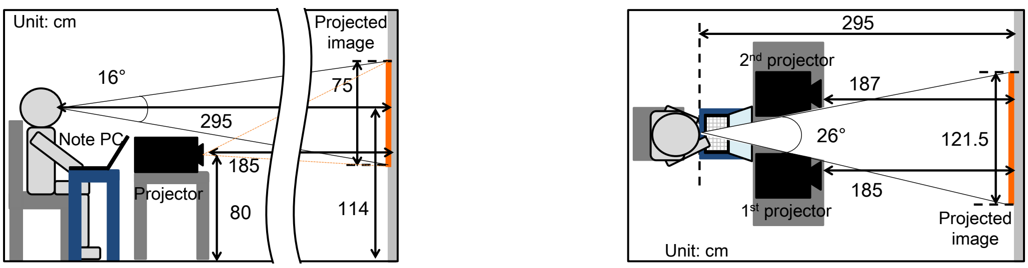
To examine the impressions provided by a gradation number increase, we performed impression assessments using various gradation numbers and assessment terms.

2.1. Environment

Our experimental assessment conditions were based on the International Telecommunication Union-Radio (ITU-R) Recommendation BT. 710 (ITU-R, 1998), in order to align our study with normal viewing conditions. The assessment conditions are listed in Table 1, while Figure 1 shows our assessment environment.

Table 1: Assessment Condition

Conditions	Values
Ratio of viewing distance to displayed image height	4.0
Maximum luminance	2.5×10^2 cd/m^2
Minimum luminance	1.5×10^{-2} cd/m^2
Contrast	Approximately 16,000:1
Illumination from other sources	3.6×10^{-1} lx
Displayed image size	55 in



(a) Right side view (b) Top side view

Figure 1: Experimental assessment environment

We performed multiple projections using two projectors (JVC DLA-X9) to create a high-gradation display device that has a maximum gradation level of 612. Our display device has a luminance range of 1.5×10^{-2} – 2.5×10^{2} cd/m^2 and a 55-in projected image size. Each projector has a resolution of 1,660 × 1,040 pixels.

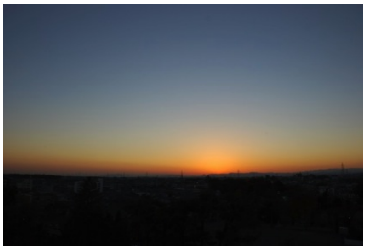
2.2. Stimuli

We used six different images, as shown in Figure 2. The stimuli included photographs of skies, skin, walls, and a spherical surface because we presumed that the gradation numbers in these images would be significant. In addition, the images of "cherry blossom" and “hand” include background blur. The background blur also produce smooth gradation change. All images were obtained from a single-lens reflex camera (Nikon D80) in 12-bit raw data at a resolution of 3,900 × 2,613 pixels.

(a) Cherry blossom

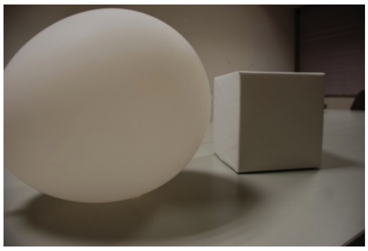
(b) Blue sky

(c) Corridor



(d) Sunset

(e) Hand



(f) Balloon and cube

Figure 2: Stimuli photographs

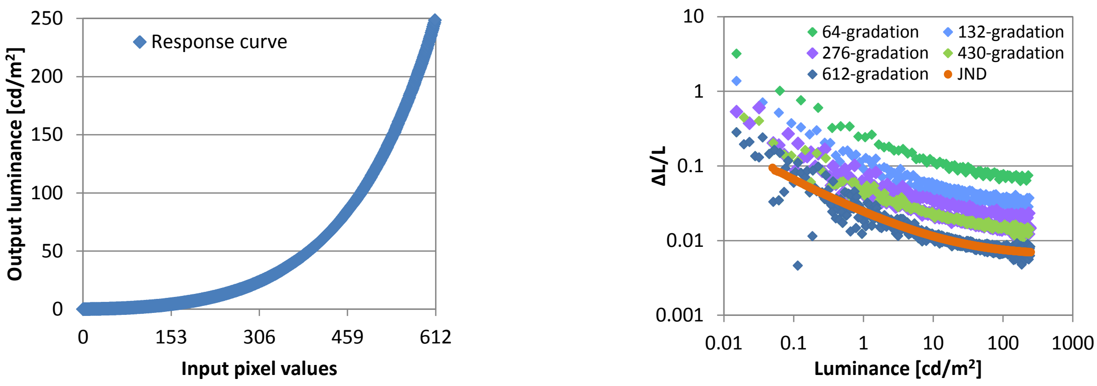
Next, we will explain how we created the input images for the two projectors.

i). We began by creating a lookup table containing the input pixel values of the two projectors and the output luminances of our high-gradation display device. The output luminances were the sum of the output luminances of the two projectors. Figure 3 (a) shows the response curve of our high-gradation display device, while Figure 3 (b) compares the luminance differences between each pixel value and the JND (DICOM, 2000). The vertical axis in Figure 3 (b) represents the luminance contrast.

ii). When creating input images, we performed inverse gamma processing because the output luminances of our high-gradation display device were not linearly changed. We then converted raw data values into input pixel values in our high-gradation display device. We also set an optional gradation number by changing the set gradation number of our high-gradation display device.

iii). Using the lookup table, we then determined the input pixel values of the two projectors using the input pixel values of our high-gradation display device.

iv). The input images of the two projectors were overlapped with each other by imposing geometric correction. Each projector projected gray-code patterns (Damera-Venkata & Chang, 2007), which were then photographed. We then performed geometric correction on the second projector's input image by using the first projector's coordinates as the standard.



(a) Response curve (b) Luminance differences (Log_{10} scale)

Figure 3: Characteristics of our high-gradation display device

Five gradation numbers (612, 430, 276, 132 and 64) were prepared. These gradation numbers were chosen because the values after inverse gamma processing are close to standard bit values (512, 384, 256, 128 and 64). As mentioned above, the luminance-difference of each gradation number is shown in Figure 3 (b). Moreover, we converted the raw data to gray scale values based on the National Television System Committee (NTSC) standard.

2.3. Assessments

We referred to a previous study (Inoue, Sotome, Sato, Ayama & Hashimoto, 2013) for the assessment terms. That study used a total of 29 words from which we selected just six ("like," "smooth," "natural," "be moving," "rough" and "dislike") because they showed conspicuous impression differences in impression assessment results. On the provided assessment sheets, we used the seven-step Likert scale. The test viewers were five men in their twenties.

First, each test subject was provided three minutes for dark adaptation. Then, the participants were asked to perform a practice session before giving their first assessment. During the actual assessment process, they recorded their judgments on provided assessment sheets. No time limits were given for making assessments. The image was presented as orders of the gradation number and the type of image differ depending on the viewer.

2.4. Results

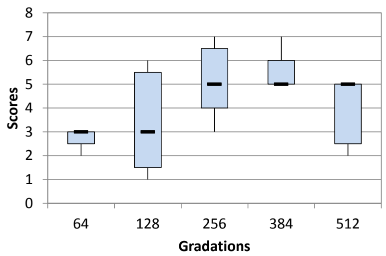
We weighted the answers from one to seven on the seven-step Likert scale, and then created box plots. The vertical line extending above and/or below the box shows the minimum and maximum, while the short horizontal line inside the box itself shows the median. The horizontal axis is the gradation number after inverse gamma processing.

Figure 4 shows the box plots results for the "blue sky" image, which showed notable trends. As can be seen in the figure, as the gradation number increased, the scores for the words "like," "smooth" and "natural" became higher, while the scores for "rough" and "dislike" became lower. This indicates that impressions improve as the gradation number becomes larger. In addition, the results show that impression trends stabilized above the 256- or 384-gradation levels. However, because no stable trends could be detected in the scores for "be moving", these words may not be suitable for use in gradation number assessments.

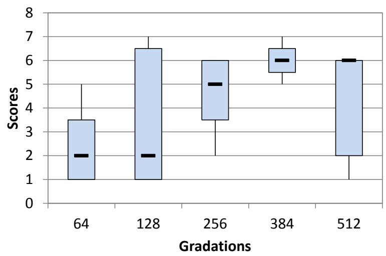
Figures 5 and 6 show the results of “smooth” and “rough” for all images. In both result sets, the “blue sky,” “corridor,” and “balloon and cube” images show strong impression trends. We believe that a common point of three images is their inclusion of a large gradation area where pixel values change gradually, such as the sky, wall, and a spherical surface. On the other hand, the “cherry blossom” and “hand” images also include gradation areas, such as background blur and skin, but no trends were recorded for these images. Therefore, it appears the viewers did not notice the changes to the gradation numbers. This, in turn, indicates that impression changes may not occur when the gradation area is small and/or situated in the background. Furthermore, while the “sunset” and “blue sky” images include similar large gradation areas, the “sunset” image showed a smaller impression trend. Thus, it can be considered likely that changes to impression trends relate to not only the gradation area size, but also to the gradation area range.

Additionally, in the “cherry blossom” result, the 64-gradation score is better than the 128-gradation score, which was significantly different from the scores recorded for other images. We think that a cause of this difference is as follows. When the viewer assessed, the other images were compared with actual views. Therefore, the viewer lowly evaluated the image including a pseudo contour appeared by the decrease of the gradation number. In contrast, an image that includes background blur is different from an actual scene. Therefore, the viewer might not perceive bad qualities from a pseudo contour that appears due to a gradation number decrease. This indicates that it will be necessary to study the effects of background blur in the future.

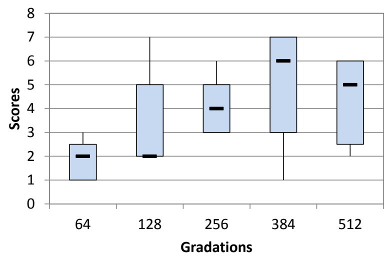
Overall, we believe that there are two reasons for the rather large score variances that were observed. The first is the small size of the sample set, the second is the fact the some viewers did not notice the pseudo contour because the gradation number change resulted in very slight differences. Hence, it will be necessary to examine the way assessments are conducted in the future.



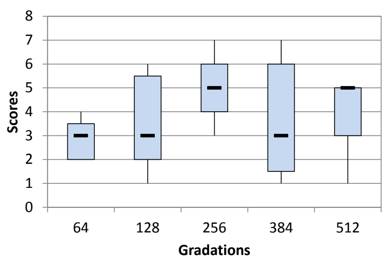
(a) Like



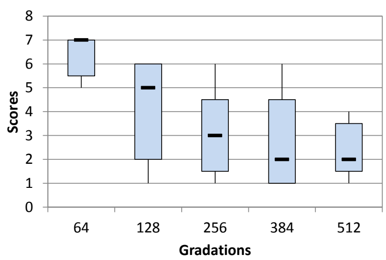
(b) Smooth



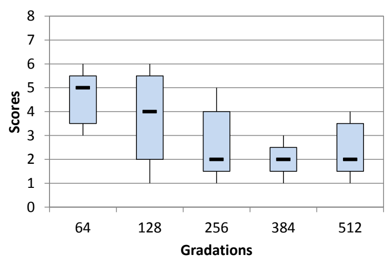
(c) Natural



(d) Be moving

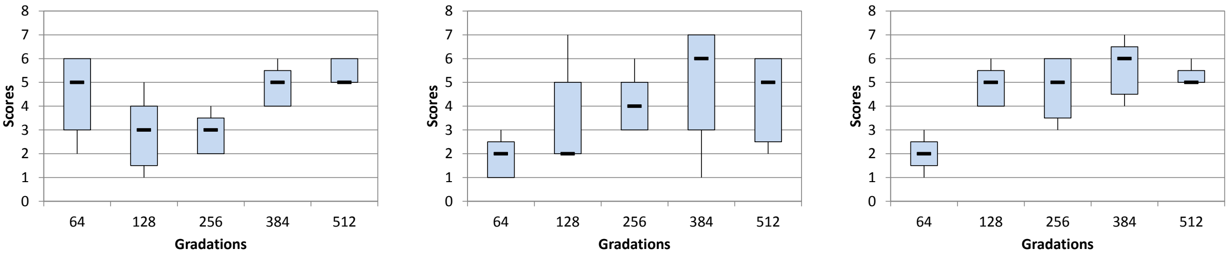


(e) Rough

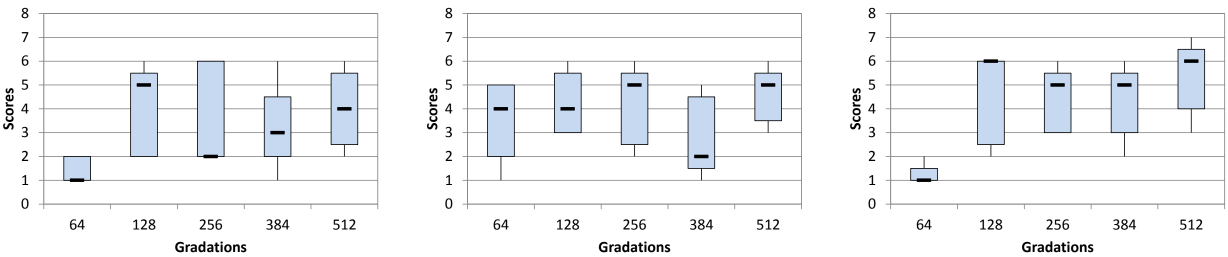


(f) Dislike

Figure 4: Box plots of the results about the image of "blue sky"

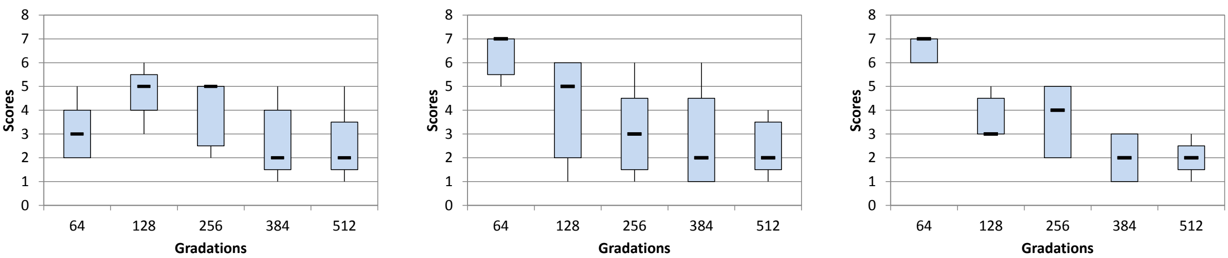


(a) Cherry blossoms (b) Blue sky (c) Corridor

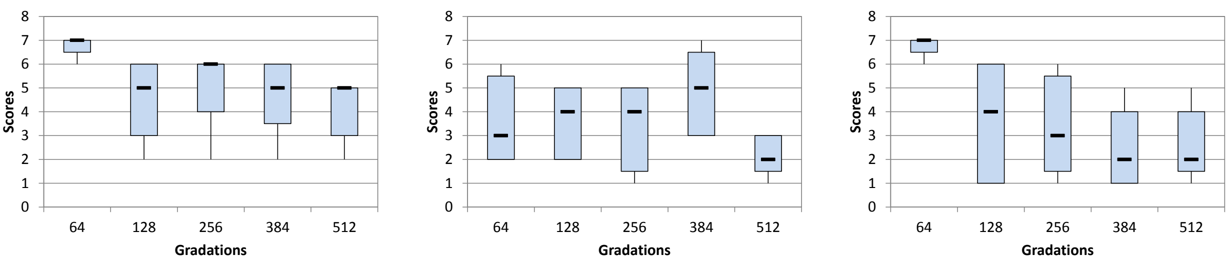


(d) Sunset (e) Hand (f) Balloon and cube

Figure 5: Box plots of the results about "smooth"



(a) Cherry blossoms (b) Blue sky (c) Corridor



(d) Sunset (e) Hand (f) Balloon and cube

Figure 6: Box plots of the results about "rough"

3. CONCLUSIONS

In this paper, we examined the impression change that results from increasing the gradation number and found that the image impressions improved as gradation numbers increased. In addition, it was determined that impressions tended to stabilize above the 256- or 384-gradation levels. In our future studies, we intend to quantitatively examine the relationship between gradation number increases and image content features using a larger sample size and a much wider selection of image types. In addition, because only gray-scale images were used in this assessment, it will be necessary to perform assessments using color and moving images in the future. Through our continued studies, we hope to indicate qualitatively effectiveness of high-gradation display devices in the general field.

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