A Fundamental Evaluation of Visual Resolution of Displays Considering Different Sub-Pixel Structures

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ABSTRACT

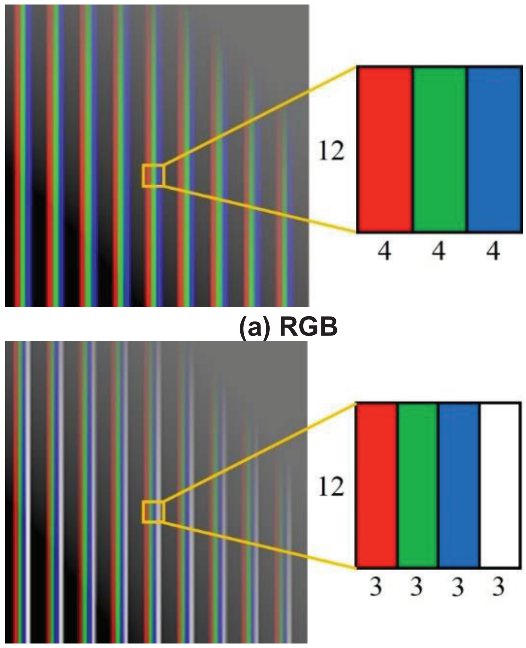
We conducted a psychometric evaluation of different display sub-pixel structures. Our assessments of the RGB sub-pixel structure showed that the vertical visual resolution was higher than the horizontal visual resolution. In addition, the visual resolution itself differed according to the sub-pixel structures.

1 INTRODUCTION

Ultra-high-definition displays (e.g., 4K and 8K displays) have gradually spread through the market, and realistic image reproduction has been accomplished. Display resolution is one of the key factors in determining the image quality, leading to a sensation of “realness” [1]. Display resolution is typically quantified as the number of pixels in the display. Recently, various sub-pixel rendering technologies have emerged beyond the traditional red, green, and blue (RGB) sub-pixel structure. Hence, the display resolution defined by pixel count has become outdated. Some studies have considered a more effective method for resolution measurement. In recent years, new visual resolution measurement methods have been proposed using the modified Landolt C [2] and luminance profile of grille pattern [3,4] to evaluate the display resolution. However, these conventional studies have not investigated the effect of sub-pixel structures for visual resolution using psychometric approaches. In the present study, we conduct psychometric assessments of the RGB and the red, green, blue, and white (RGBW) sub-pixel structures and investigate the effects on the visual resolution.

2 EXPERIMENT

We prepared white and black line pairs with two types of sub-pixel structures to represent the horizontal and the vertical directional stripes as the visual test pattern. One of the sub-pixel structures was the traditional RGB. The other one had four primary colors for a pixel (RGBW). In our experiment, one pixel in the real display resolution was assumed to be a virtual sub-pixel to represent both the sub-pixel structures. Both the pixel pitches were equivalent, representing one pixel with 12 × 12 virtual sub-pixels (Fig. 1). For each sub-pixel pattern, we prepared horizontal and vertical directional stripes. Therefore, all test patterns consisted of four types of stripes (horizontal/vertical stripes with RGB/RGBW sub-pixels). As a fundamental evaluation, we conducted psychometric assessments on a pair of stripes in a circular shape with these four types of stripes displayed at the left and at the right on a high-definition monitor (Eizo ColorEdge CG248-4K). In our assessments, we conducted two types of experiments to investigate the difference in visual resolution for stripe directions and sub-pixel structures.



(a) RGB

(b) RGBW

Fig. 1 Pixel structure of visual test patterns

2.1 Experiment A: Comparison according to stripe directions

To compare the difference in visual resolution for different stripe directions with the same sub-pixel structure, we prepared four types of stimuli in each sub-pixel structure (RGB and RGBW). We arranged the vertical and the horizontal directional stripes on the left and the right as follows:

- RGB vertical stripe vs RGB horizontal stripe
- RGB horizontal stripe vs RGB vertical stripe
- RGB vertical stripe vs RGB vertical stripe
- RGB horizontal stripe vs RGB horizontal stripe

Observers responded with a two-alternative forced choice (2AFC) task, where the left and the right stripes were clearly perceived. The background color of the test

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patterns was kept equal to the average of the black and the white luminance. Therefore, whenever an observer could not perceive the stripe, the border between the test pattern and the background could not be distinguished. The test patterns were shown in a darkroom. The viewing distance between the monitor and the observer's eye was set to 3.77 m, 4.71 m, and 5.65 m, corresponding to 20 cpd, 25 cpd, and 30 cpd, respectively. The diameter of the circular test patterns was 1800 virtual sub-pixels (24.7 cm in actual size). Between the test patterns, the observers were shown a uniform background color to remove the influence of the previous observation (an afterimage). To avoid any effects of the non-uniformity of the luminance distribution on the monitor, the assessment was made again by rotating the monitor upside down. This evaluation procedure was repeated twice to ensure response stability. Each stimulus was randomly presented 28 times. Two observers with a normal color vision and visual power participated in this experiment.

2.2 Experiment B: Comparison according to the sub-pixel structures

To compare the difference in visual resolution for different sub-pixel structures with the same directional stripes, we prepared four types of stimuli in each direction (vertical and horizontal stripes), arranging the RGB and the RGBW sub-pixels on the left and the right as follows:

- RGB vertical stripe vs RGBW vertical stripe
- RGBW vertical stripe vs RGB vertical stripe
- RGB horizontal stripe vs RGBW horizontal stripe
- RGBW horizontal stripe vs RGB horizontal stripe

In addition, 4 types of stimulus-pairs with the same directional stripe and the same sub-pixel structure were prepared as follows:

- RGB vertical stripe vs RGB vertical stripe
- RGB horizontal stripe vs RGB horizontal stripe
- RGBW vertical stripe vs RGBW vertical stripe
- RGBW horizontal stripe vs RGBW horizontal stripe

These eight stimuli were presented 32 times in random order to the observers. The experimental environment and the observers were the same as those in Experiment A.

3 RESULTS

The average response rates in Experiment A for comparison of the difference in visual resolution for the different stripe directions are shown in Fig. 2. Figure 2(a) for the RGB sub-pixel structure shows that the average response rate in the vertical stripes was higher than that in the horizontal stripes. Remarkably, a significant difference was observed at shorter viewing distances such as 20 cpd and 25 cpd. This result indicates that the visual resolution for the vertical direction is perceptually higher than that for the horizontal direction in the RGB sub-pixel structure. In contrast, in case of the RGBW sub-pixel structure, no significant difference was observed in the visual resolution for the vertical and the horizontal direction.

The average response rates in Experiment B for the comparison of the sub-pixel structures are shown in Fig. 3. Figure 3(a) confirms that the average response rate with the RGB sub-pixel structure was significantly higher than that with the RGBW sub-pixel structure for the vertical stripes. This result indicates that the visual resolution for the RGB sub-pixel structure is perceptually higher than that for the RGBW sub-pixel structure in the vertical direction. In contrast, no significant difference was observed in the visual resolution between the RGB and the RGBW sub-pixel structures in the horizontal direction. Figure 3(b) shows that there was no significant difference in perception between the left and the right display stimuli in the present experiment.

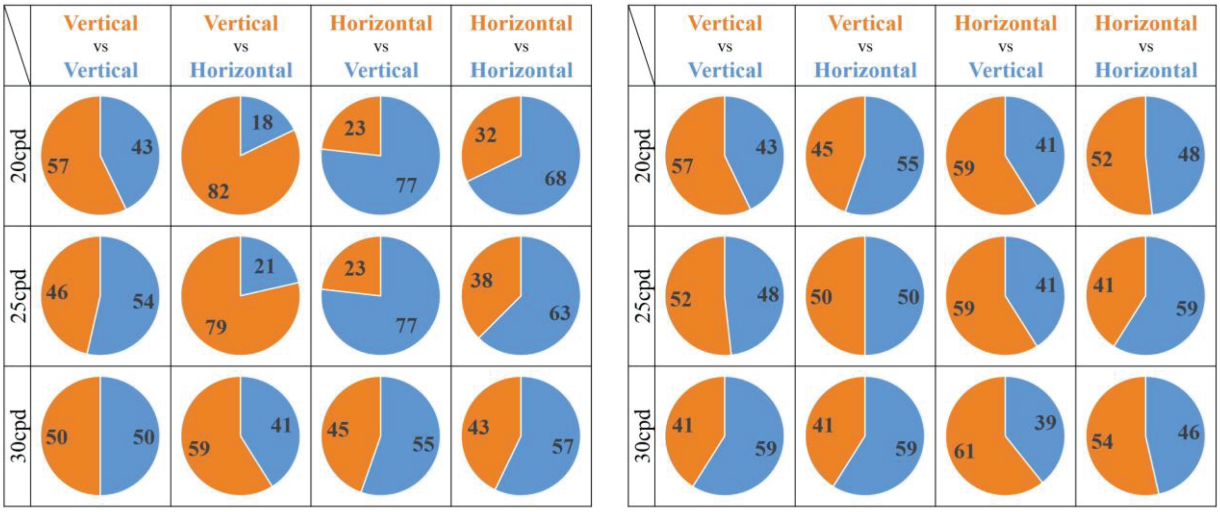
4 DISCUSSION

Through organization of the results for Experiments A and B, it can be concluded that the highest visual resolution was observed for the vertical direction with the RGB sub-pixel structure among the different combinations. The ITU-R Recommendation BT.2035 suggests an image resolution of one arc-minute (30 cpd) as the criterion for viewing conditions when assessing displayed image quality. In addition to the criterion, our results indicate that sub-pixel structures should be considered for the assessment.

Various metrics have been proposed for evaluating the display resolution using physical or psychometric approaches. We evaluated the influence of the sub-pixel structures on the visual display resolution. We conducted assessments of two types of sub-pixel structures (RGB and RGBW) by considering 12 actual pixels of the display monitor as one virtual pixel. We succeeded in achieving virtual recognition of the sub-pixel array at an observation distance 12 times the original distance. We found that the visual resolution might differ depending on the differences in the sub-pixel structures. For example, the vertical resolution with the RGB sub-pixel structure was the clearest among the test patterns in this study. Using the present approach, we can evaluate the visual resolution of display devices with arbitrary sub-pixel structures.

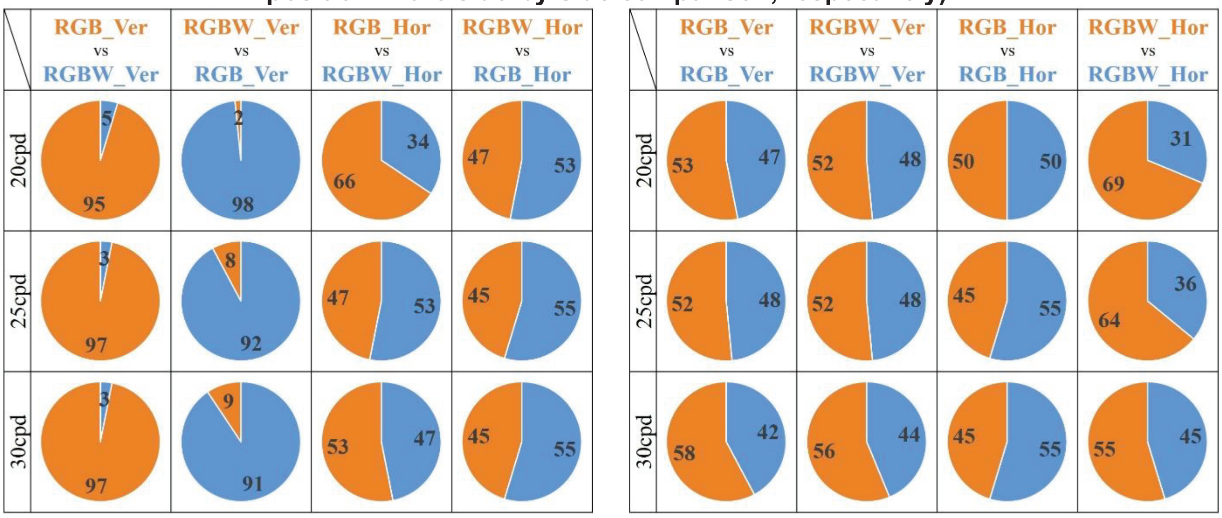
5 CONCLUSIONS

In this paper, we conducted psychometric assessments of the RGB and the RGBW sub-pixel structures and investigated the effects on visual resolution. The vertical visual resolution was higher than the horizontal visual resolution with the RGB sub-pixel structure. However, there was no significant difference in the visual resolution for the RGBW sub-pixel structure. Moreover, in the vertical direction, the visual resolution with the RGB sub-pixel structure was higher than the resolution with the RGBW sub-pixel structure. According to these results, the vertical visual resolution with the RGB sub-pixel structure was the most visible among the present experimental stimuli. These results suggest that



(a) RGB **(b) RGBW**

Fig. 2 Response rates for Experiment A (orange and blue colors show the left and the right position in the side-by-side comparison, respectively)



(a) Different sub-pixel structures with the same direction **(b) The Same sub-pixel structure and direction**

Fig. 3 Response rates for Experiment B (orange and blue colors show the left and the right position in the side-by-side comparison, respectively)

visual resolution may vary as a function of sub-pixel structure differences. As a next step in this investigation, we will investigate the visual resolution using other sub-pixel structures to facilitate fair evaluation of the display resolution with various sub-pixel structures in the future.

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