Comparison of Color Perception of Scene Images between Head-Mounted Display and Desktop Display

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ABSTRACT

In this paper, subjective evaluation experiments using scene images were conducted to investigate the difference of luminance and chroma perception between an HMD and a desktop display. The results showed that the perception of luminance and chroma of the HMD were higher compared with those of the desktop display.

1 INTRODUCTION

Image and graphics contents with Virtual Reality (VR) technologies have been developed rapidly. Since recent reproduction performances in virtual reality spaces (VR spaces) has been improved, high-realistic movies, video games, etc. can be provided. For examples, Grantcharov et al. reported that the performances of surgeon laparoscopic exercises were improved by using VR training system [1]. Itoh et al. proposed a virtual restoration system for historic buildings under the VR environment [2]. Messner et al. introduced a task that constructing a 4D CAD model (a 3D CAD model with time series data) to the students of the faculty of architecture, and tested the performance of the CAD model in a VR space. As a result, after the confirmation in the VR space, the identification rate of the contradictory part clearly increased. They finally summarized that the VR technology is useful for education in the field of architecture [3]. As shown in above examples, VR technologies are useful for providing new experiences. However, it is also known that head-mounted displays (HMDs) often causes discomfort experiences such as VR sickness. Koulieris et al. designed a display module that could provide the consistency between the both eye functions according by combining an automatic refractometer and HMD [4]. They also confirmed the reduction of discomfort through evaluation experiments.

For improving the reality in HMDs, it is a significant work to addressing the appearance in VR spaces. Pedro et al. compared the appearance between VR scene and Real scene using HMD through subjective evaluation experiments [5]. However, there are no detailed investigations on color perception between HMDs and ordinary displays. In VR spaces, we observe virtual images through the lens on the HMD. Also, the virtual distance to the object is controlled by the tracking sensor, although the real distance to the screen plane in the HMD and the refractive index of the lens do not change. In this way, even if color images of HMDs are accurately reproduced based on colorimetry, the perception of luminance and chroma may be different. In other words, the differences of optical systems between HMDs and ordinary displays will affect the color perception. Therefore, we investigated the appearance of color patches between real space and VR space in our previous study [6]. The results showed the perception of luminance and chroma of the color patches on an HMD is higher compared with those on a desktop display.

In this study, based on our previous study based on color patches, we investigated color appearance using scene images which were displayed on a HMD. Color matching experiments using scene images are conducted to clarify the differences of luminance and chroma perception between an HMD and a desktop display. Thus, we analyze and discuss color appearance differences between an HMD and a desktop display in terms of luminance and chroma.

2 EXPERIMENT

2.1 Experimental overview

In order to investigate the differences of luminance and chroma perception between an HMD and a desktop display, color matching experiments using scene image stimuli were conducted. In our experiments, we used two group of scene image stimuli. The first group (Group1) consisted of scene images which were generated by modifying HSV from a single scene image (7 scenes in total). The second group (Group2) consisted of a different scene images (7 scenes in total). The examples of scene images are shown in Fig.1. In these experiments, colorimetric values were measured using a spectral radiometer Konica Minolta CS-2000. The desktop display was EIZO ColorEdge CG 277 and the HMD was Oculus Rift DK 2. The gamuts of both displays are shown in Fig.2. Five subjects with normal color visions participated in the experiments. The actual experimental environment is shown in Fig. 3. The experiments were conducted in a dark room.

2.2 Experimental setup

The viewing distances between an observer and a desktop display was 0.3 m. This condition corresponded to 70 visual degrees. In this experimental conditions, subjects could ignore the environmental influence outside the desktop display. Also, 70 visual degrees to a desktop display are close to the visual degrees in the HMD. The stimulus image on the HMD was generated

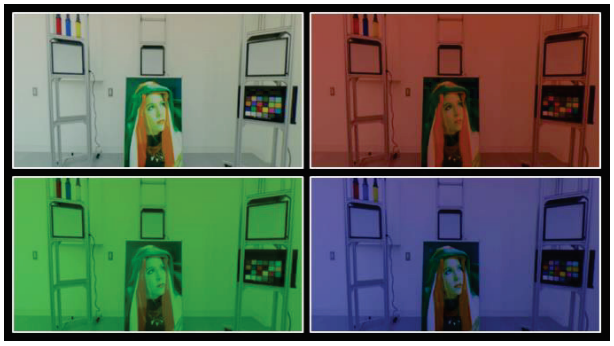
by Unity. We also displayed the visually-equivalent size on the both display. For all of scene images, a color matching experiment was conducted according to the procedure in Section 2.3.

2.3 Experimental procedure

Both groups of scene image stimuli (Group1 and Group2) were conducted in the following procedure.

1. Compare scene image stimuli displayed on both the HMD and the desktop display.
2. Adjust luminance and chroma of the scene image stimulus on the desktop display by operating a GUI slider.
3. Compare luminance and chroma on both displays and repeat Step 2 until the luminance and chroma become equivalent.

Before starting the experiment, the subjects were instructed and trained to change luminance and chroma by using the experimental GUI. In this training, we prepared test scene images (the scene image stimuli in the actual experiments were not used). During the experiment, subjects could freely compare color appearance of the scene image stimuli on both displays. When comparing scene images with a desktop display and an HMD, subjects could compare 360° omnidirectional scenes. On the desktop display, subjects could view the scene by dragging the mouse. In HMD, subjects can look over the scene by moving the head. However, we did not instruct subjects to look around the scene for the comparison.



(a) Group 1

(b) Group 2

Fig. 1 Examples of scene images in our experiments

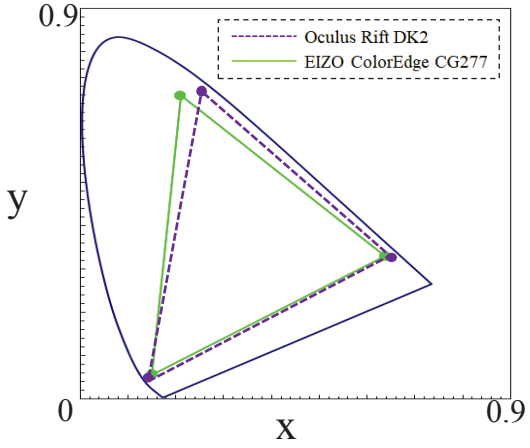


Fig. 2 Color gumat of both displays

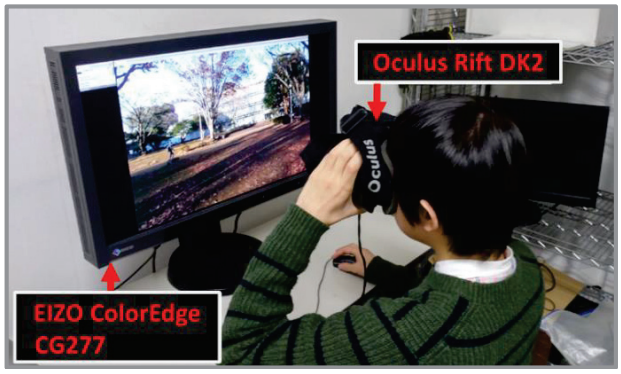


Fig. 3 Experimental environment

3 RESULTS and DISCUSSIONS

3.1 Experimental results

The tristimulus values of the image stimuli were measured with a spectral radiometer. The average of L*a*b* values (the subjects' averages) were obtained. The comparative results of the evaluated L*a*b*values are shown in Figs. 4 and 5. As shown in Fig. 4(a), for all of the 7 scene image stimuli used in Group 1, the perceived luminance of the subjects' averages on the desktop display was higher than the luminance of the scene image stimuli on the HMD. This results suggest that the luminance perception on the HMD was higher than that of the desktop display. Furthermore, from Fig. 4(b), the subjects' averages were higher than the HMD in chroma perception, while keeping the same hue. Also, as shown in Fig.5, similar results to Group 1 were obtained in luminance and chroma perception in the results of Group 2.

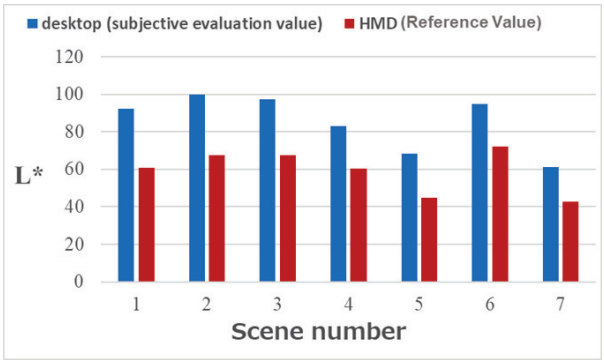
3.2 Discussions

Experimental results using scene images suggested that the luminance and chroma perception of an HMD were higher than those of a desktop display, even though color perception of scene image stimuli were equally displayed on HMD and desktop display. In our previous

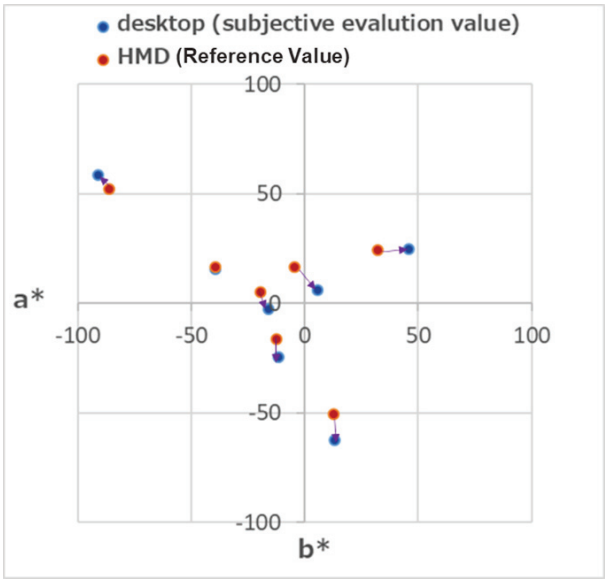
study using patch images [6], it was suggested that luminance and chroma perception of an HMD higher than those of a desktop display when using scene images. In summary, color perception in HMDs with not only patch images but also scene will be brighter and more vivid compared with ordinary desktop displays such as LCDs.

In order to discuss the results, we consider the differences of optical systems between HMDs and desktop displays. Schematic diagrams of the optical systems are shown in Fig.5 (a). A_R and A_{VR} are viewing area, d_R and d_{VR} are viewing distance, α is a distance from a screen plane to the lens in an HMD, and f is the focal distance of the lens.

The pupil area when viewing the desktop display was actually measured using the eye tracking measurement device EMR-9. On the other hand, the pupil area when viewing the HMD was calculated based on the viewing of the desktop display with the viewing distance of the actual display plane in the HMD. A temporal change of the pupil diameter in the measurement is shown in Fig.5 (b). The average were 4.08 [mm] and 4.43 [mm] for the desktop display and the HMD, respectively. This result implies that an amount of light flux (retinal illuminance) into the HMD is larger than that of the desktop display. Generally, in color perception, Stevens effect and Hunt effect are stronger. Stevens effect shows that contrast and perceived luminance increase with luminance level, and Hunt effect shows that contrast and perceived chroma increase with luminance level. We consider that the both effects work on the retina when viewing the HMD. Thus, we have obtained the results of Fig.4 and Fig.5 which show luminance and chroma perception in the HMD was higher than those of the desktop display.

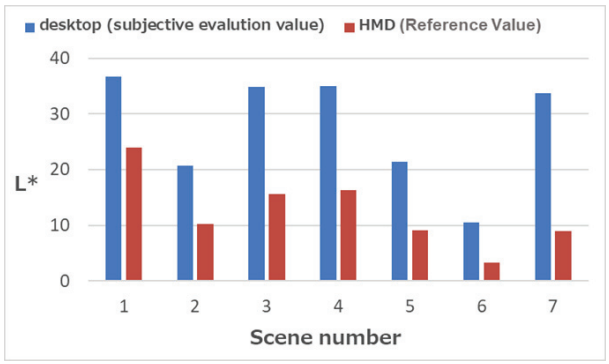


(a) Luminance

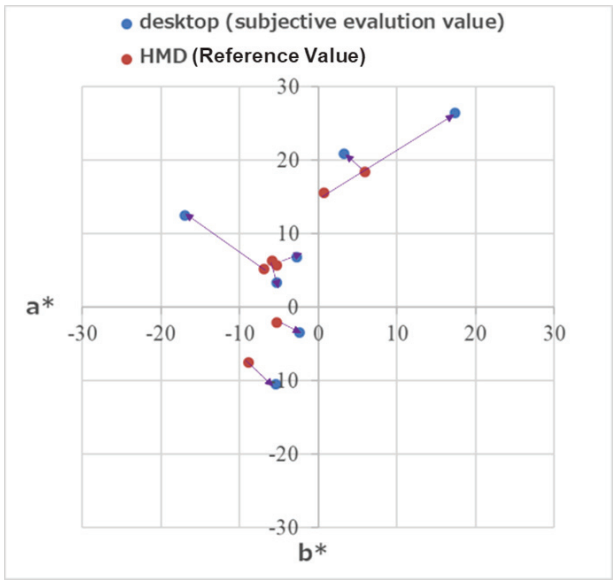


(b) Hue and saturation

Fig. 4 Experimental results with images of Group1. Luminance and saturation difference when subjects perceive luminance and chroma of each scene image stimulus are equal on the HMD and desktop display

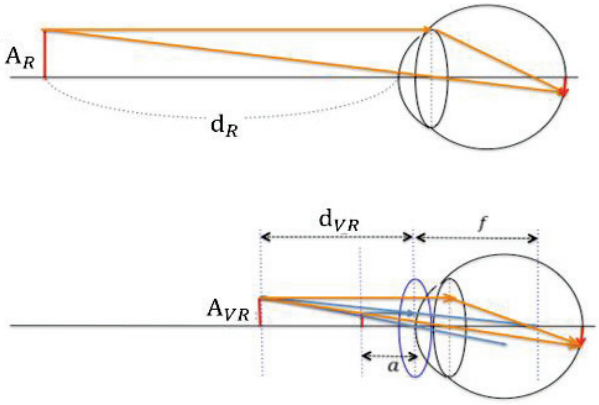


(a) Luminance

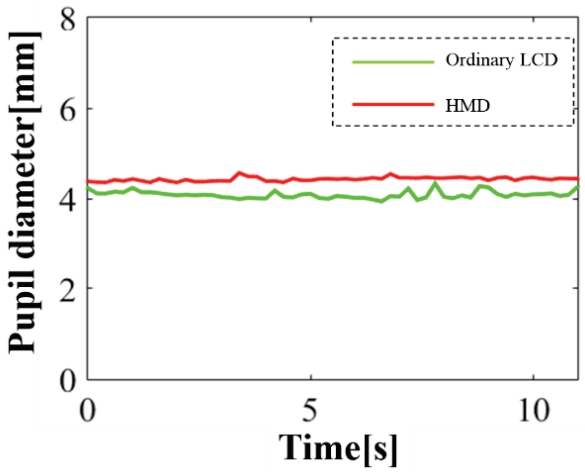


(b) Hue and saturation

Fig. 5 Experimental results with images of Group2. Luminance and saturation difference when subjects perceive luminance and chroma of each scene image stimulus are equal on the HMD and desktop display



(a) Optical system
(Upper fig: desktop, lower fig: HMD)



(b) Measurements of pupil diameter
Fig. 6 Optical system and pupil size

4 CONCLUSIONS

In this paper, we investigated the differences of luminance and chroma perception between an HMD and a desktop display when using scene images through color matching experiments. As the results, luminance and chroma perception of the HMD were higher than those of the desktop display when using scene image stimuli. These results were similar to our previous study using color patch stimuli [6].

Also, we schematized the optical system and suggested a hypothesis that the differences of the optical systems on HMDs and desktop displays influenced luminance and chroma perception. Based on the result of the pupil diameter measurement, the amount of light flux (retinal illuminance) that was the incident light into an eye was estimated. As a result, the amount of light flux was larger on an HMD. Therefore, we consider that Stevens effect and Hunt effect worked much on an HMD, and observers perceived higher luminance and chroma on an HMD compared with a desktop display.

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