Measurement of Lens Accommodation and Convergence during the Viewing of 3D Images

Takumi Oohashi[1], Hiromu Ishio[2], Yuki Okada[1], Tomohiko Yanase[1], Takehito Kojima[1], and Masaru Miyao[1]

[1] Graduate School of Information Science, Nagoya University, Nagoya, 464-8603, Japan
[2] Urban management department, Fukuyama University, Fukuyama, Hiroshima 721-0964, Japan
oohashi.takumi@a.mbox.nagoya-u.ac.jp,
{f.ibl.1989,kisa2015,tkojima45}@gmail.com,
miyao@nagoya-u.jp,
h-ishio@fcu.ac.jp

Abstract. Three-dimensional display technology has developed rapidly in recent years. This has been accompanied by increasing problems of visual complaints such as eye strain. There are also various types of digital signage, in which text information moves on a screen. In this paper, we conducted two experiments for the purpose of easy to read, dynamic characters that pop out when viewing 3D images, and safe and comfortable 3D viewing. We conducted a survey of accommodation and convergence of viewers when they watched a movie with a television opaque projector for large outward projection of characters. We also compared the results of a survey on the readability of characters that pop out and the proportion and the perception of the amount of protrusion. We examined the maximum distance in which subjects' eyes could recognize the 3D character representations without any difficulty or discomfort. The distance of the images as they popped out from the screen as a theoretical virtual target was compared with what the subjects recognized according to each age group. There was no significant difference between the theoretical and observed values in any age groups. In a second experiment, we performed objective measurements of accommodation and convergence for 3D character representation using original instruments. We then compared the values of the measurements of the subjects with the theoretical positions of emergence. When a subject recognized a 3D character representation, the position of his or her accommodative and convergent focus was closer to the theoretical position of the virtual object that projected out from the screen. Nearly all of the subjects recognized the 3D representation at even 3.8 degrees, which was the largest parallax condition. Cognitively, almost all of the subjects viewed the positions of the objects correctly without much difficulty.

Keywords: 3Ddisplay, ergonomics, accommodation, convergence.

C. Stephanidis and M. Antona (Eds.): UAHCI/HCII 2013, Part II, LNCS 8010, pp. 309–317, 2013.

1 Accommodation and Convergence

1.1 Mismatch Theory of Accommodation and Convergence

Stereoscopic vision is generally explained as follows: During natural vision, lens accommodation (Fig. 1) is consistent with convergence (Fig. 2). During stereoscopic vision, while accommodation is fixed on the display that shows the 3D image, convergence of the left and right eyes crosses at the location of the stereoimage, or the focus of accommodation and convergence floats between the screen and the position of a virtual target and is pulled by convergence. Hence, accommodation and convergence are mismatched. This is the main reason for the visual fatigue caused by stereoscopic vision [1-4]. Advocates of these theories warn that because of the hazards associated with such a discrepancy, there should be a limitation on the distance that an object pops out from a screen in a 3D image. According to national safety guidelines on 3D images in Japan, a safe range for the parallax for viewing 3D images is less than 1 degree because of above mentioned "accommodation-convergence discrepancy." However, we denied this discrepancy in previous papers.

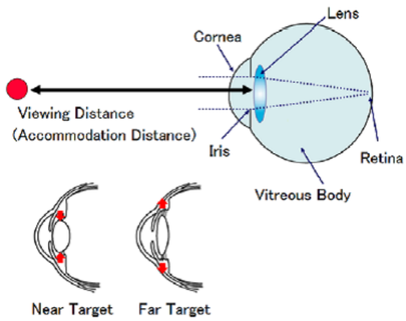

Fig. 1. Lens Accommodation

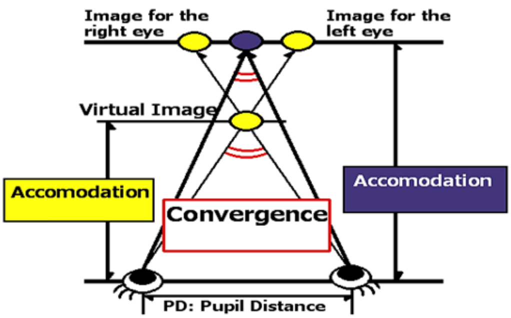

Fig. 2. Convergence

1.2 Demonstration of Accommodation and Convergence Adjustment in Previous Research

According to the findings presented in our previous reports, however, explanations such as those above are mistaken [5, 6]. It is also commonly said that if accommodation coincides with convergence and focuses on the fusional points of stereoimages, focus is not on the display and blurred images are seen. This can happen occasionally and is a cause of visual fatigue. According to our findings presented in a previous report, however, this theory is also mistaken [7]. Nevertheless, it is still often said that the mismatch between accommodation and convergence is the main reason for visual fatigue. This may be because the experimental evidence obtained in our previous studies, where we did not measure accommodation and convergence simultaneously, was not strong enough to convince people.

In young people accommodation distances are nearly consistent with the distance from the subject to the object, often located a little beyond the object [8]. Perhaps this originates from the fact that subjects see the index even when the focus is not accurate because of the depth of field. On this point, this fact appears nearly in agreement with our previous findings [9, 5] which indicate that the lens may not be accommodated strictly at about 0.4 D.

We used a ticker jumping out from the screen with a very large disparity in this experiment. Our aim was to show the safety of the ticker jumping out from the screen dynamically by moving the focus of the focus adjustment and congestion in synchronism with the position of the character.

2 Experiment 1: Recognition of Outward Projecting Virtual 3D Text

2.1 Method

The aim of this study was to observe the reading of characters and the ease of reading on different display types for 3D images. The experiment investigated the distance of emerging 3D images by using character information that projected from the background of stereoscopic images.

We carried out experiments with 133 healthy volunteers between the ages of 19 to 85 years, with their pre-informed consent. The study was approved by the ethics committee of the Graduate School of Information Science, Nagoya University.

In the first experiment, the subject was seated in a chair viewing the front of the display with a 3D shutter glass. The viewing distance from the screen was set to 186 cm (Fig. 3). The outward projecting character and background were in different parallax. At the start we confirmed whether or not the subject was able to perceive 3D fusion. The subject indicated the distance from the screen and the emerging image by using a pointer.

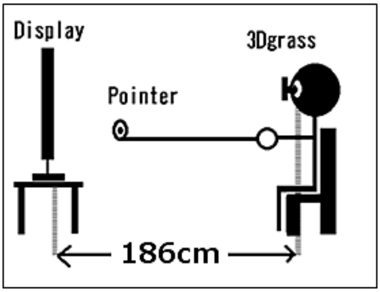

Fig. 3. Experimental setup

Subjects were all assumed to view the 3D image with four random disparities. The width of the parallax was 1.8°, 2.4°, 3.1° and 3.8° diagonal to the display (Fig. 4). Each image was shown for approximately 30 seconds. The characters that popped out were all the same. The parallax is the ratio of the length to the diagonal of a 50-inch television, and the viewing distance is assumed in the 3H = 186 cm.

3D images were displayed using a liquid crystal shutter. A Panasonic 50-inch display (Model TH-P50VT5, 110.6 cm × 62.2 cm, resolution: 1920 × 1080) was used for the playback device with a Panasonic Blu-ray Disc Player™.

The brightness of the background was 13.3 cd/m^2 and that of the characters was 10.0 cd/m^2. The illuminance of the display surface was 342 ℓx. Environmental illuminance was 668 ℓx.

Fig. 4. Image and content

2.2 Results and Discussion

We obtained data from 116 individuals. We ranked the subject by age as young (19-44 years, 50 subjects), middle-aged (45-64 years, 36 subjects), and old-age (65-85 years, 30 subjects). There were 50 male subjects and 66 female subjects. The number of individuals with a pupil distance shorter than 60 mm was 41, the number with a distance of 61-64 mm was 40, and the number with a distance over 65 mm was 27. Four could not successfully complete the test because of stereopsis. In 12 subjects the fusion of the right and left eye may have been broken because the subject happened to watch the pointer.

Most of the subjects were able to recognized the set parallax conditions of 1.8°, 2.4°, 3.1°, 3.8°, and in all conditions most of the subjects recognized the 3D character that popped out. The position of the viewed projected image was generally correct.

For all age groups, there was no disparity in the conditions between the theoretical and observed values with a 1.96 SD average, and the test was above the 95% confidence level. The recognition error was about 3-5cm (Fig. 5). The change in the difference between the theoretical and the observed values was assayed by ANOVA to compare the amount of parallax of the emerging objects. No significant difference in parallax error was seen in any of the conditions.

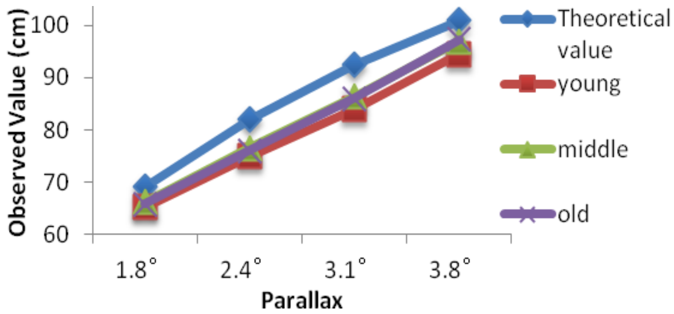

Fig. 5. Observed values by Age

3 Experiment 2: Simultaneous Measurement of Lens Accommodation and Convergence to 3D

3.1 Method

Among younger subjects, the recognized focus of the 3D characters appeared to be closer to the screen than the theoretically obtained positions.

In Experiment 2, we performed objective measurements of accommodation and convergence for 3D character representation using young subjects. We measured the accommodative and convergent focus using original instruments.

The devices used in this experiments were an auto ref/keratometer, WAM-5500 (Grand Seiko Co. Ltd., Hiroshima, Japan) (Fig. 6) and an eye mark recorder, EMR-9 (NAC Image Technology Inc., Tokyo, Japan) (Fig. 7). WAM-5500 enables continuous recording at a rate of 5 Hz for reliable and accurate measures of accommodation. EMR-9 can measure convergence distance using the pupillary/corneal reflex method. Subjects were given a full explanation of the experiment in advance and consent was obtained. Subjects used their naked eyes or wore soft contact lenses as needed, and their refraction was corrected to within ±0.25 diopter (a "diopter" is the refractive index of lens. It is an index of accommodation power, and the inverse of meters.).

The WAM-5500 and EMR-9 devices were combined, and we simultaneously measured the focused distances of accommodation and convergence when subjects were gazing at objects (Fig. 8).

Fig. 6. Auto ref/keratometer WAM-5500 (Grand Seiko Co. Ltd.)

Fig. 7. EMR-9 (NAC Image Technology Inc.)

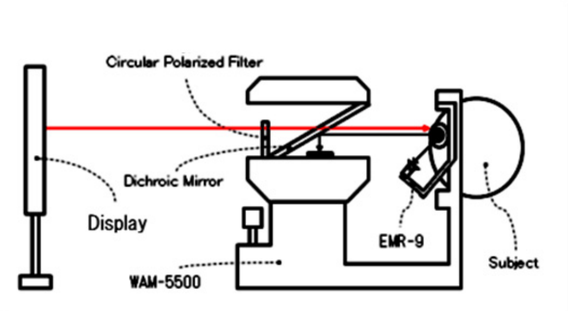

Fig. 8. Pattern diagram of measurements

We carried out experiments with 7 persons between the ages of 19 to 35 years with their pre-informed consent. This study was approved by the ethics committee of the Graduate School of Information Science, Nagoya University.

In the experiments, the subject was seated in a chair viewing the front of the display. The viewing distance from the screen was set to 156 cm. Subjects were all assumed to view 3D images of four random disparities. The length of the parallax was 1.8°, 2.4°, 3.1° and 3.8° diagonal to the display (Fig. 4). Each image is approximately 30 seconds in length. The characters that popped out were all the same, and they appeared and disappeared. Parallax is the ratio of the length to the diagonal of a 42-inch television, and the viewing distance is assumed with 3H = 156cm.

A 3D display method was carried out with the circular polarizing filter system. An LG 42-inch display (Model 42LW5700-JA, 93.0cm × 52.3cm, resolution: 1920 × 1080) was used for the playback device with a Panasonic Blu-ray Disk Player.

The brightness of the background was 97.5 cd/m^2 and that of the character was 4.5 cd/m^2. The illuminance of the display surface was 291 ℓx. Environmental illuminance was 800 ℓx.

3.2 Results and Discussion

When viewing 3D images in parallax 1.8°, the theoretical values of accommodation and convergence are about 1.0 Diopters (98 cm). Subject A (24 years old, male, soft contact lenses) viewed the 3D image in parallax 1.8° (Fig. 9) with the accommodation narrow changed near about 0.8 Diopters (125 cm), and convergence narrow changed near about 1.3 Diopters (77 cm). The observed value was about 0.94 Diopters (106 cm). These values are within the range of depth of field as described in Section 2. Accommodation and convergence changed in almost the same way.

When viewing 3D images in parallax 3.8°, the theoretical value of accommodation and convergence are about 1.4 Diopters (71 cm). Subject A viewed the 3D image in parallax 3.8° (Fig. 10) with the accommodation narrow changed near about 1.0 Diopters (100 cm), convergence narrow changed near about 1.4 Diopters (71 cm). The observed value was about 1.23 Diopters (81 cm). These values are also within the range of depth of field. Accommodation and convergence also changed in almost the same way.

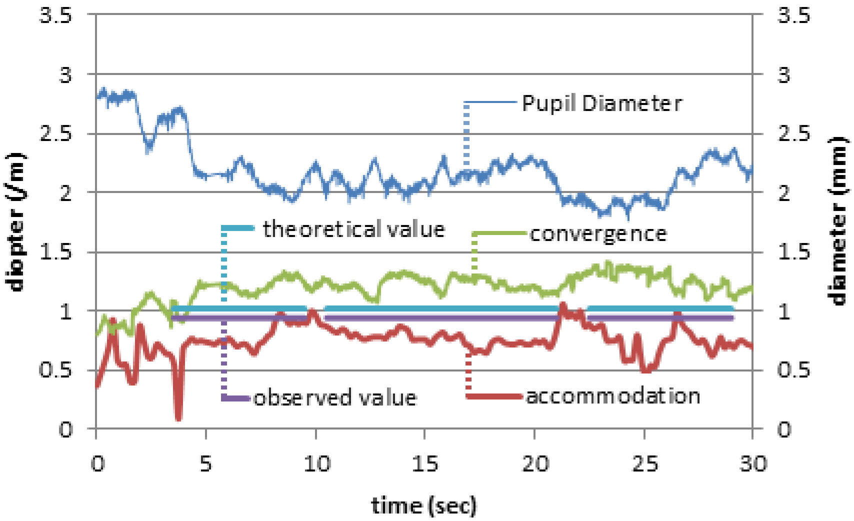

Fig. 9. Example of measurements: Subject A: 1.8° Parallax

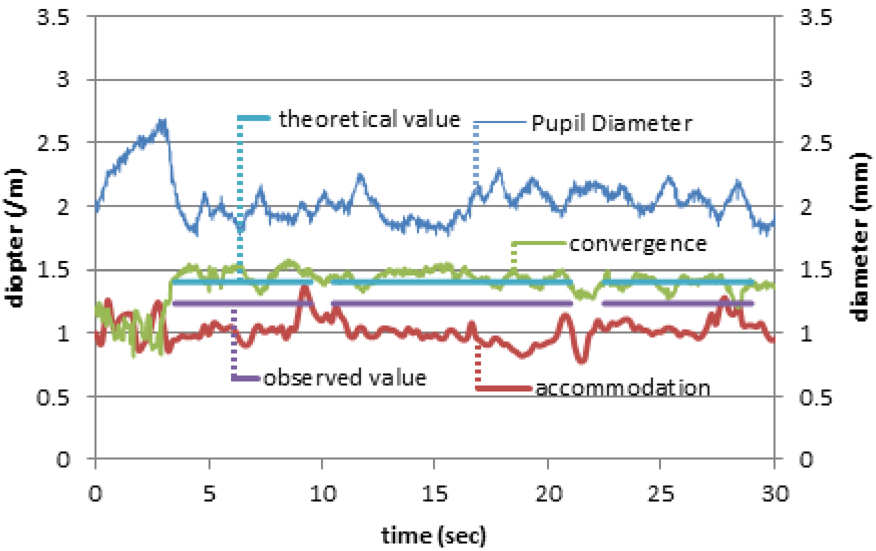

Fig. 10. Example of measurements: Subject A: 3.8° Parallax

The changes in the respective diopter values have almost the same amplitude and are in phase, corresponding to appearance of the 3D character image. The results of the other subjects and for other parallax were roughly consistent with Subject A.

From the results in Figs. 10 and 11, we see that when young subjects view 3D images accommodative power is consistent with the distance of convergence for the contents of 3D characters in parallax 1.8°~3.8°, and that the values of focal distances are synchronized with each other.

4 Summary

The findings in these two experiments showed that regardless of how much a 3D image appeared to emerge from a screen (parallax of 1.8, 2.4, 3.1 and 3.8 degrees), subjects in all age groups were able to recognize the character representations. Objective measurements of accommodation and convergence for 3D character representation were also performed with young subjects. When a younger subject recognized a 3D image, the position of his or her accommodative and convergent focus was closer to the theoretical position of a virtual object popping out from the screen. The results from this experiment show that even with a 3.8° disparity, people can also perceive the 3D character representations without any difficulty or discomfort. Thus, we showed that most subjects could recognize 3D images even when an image emerges from a large distance.

Finally, only one subject, aged in his twenties, complained of discomfort in viewing the objects for a short time in the experiment.

Acknowledgements. We are deeply grateful to Prof. Sakuichi Otsuka, Kagoshima University, and Prof. Yuji Sakamoto, Hokkaido University, whose comments and suggestions were of inestimable value for this study. This research was partially supported by JSPS Kakenhi (B) Number 24300046 and 23300032.

References

1. Wann, J.P., Rushton, S., Mon-Williams, M.: Natural Problems for Stereoscopic Depth Perception in Virtual Environments. Vision Res. 35(19), 2731–2736 (1995)
2. Watt, S.J., Akeley, K., Ernst, M.O., Banks, M.S.: Focus Cues Affect Perceived Depth. Journal of Vision 5, 834–862 (2005)
3. Hoffman, D.M., Girshick, A.R., Akeley, K., Banks, M.S.: Vergence-Accommodation Conflicts Hinder Visual Performance and Cause Visual Fatigue. Journal of Vision 8(3), 33, 1–30 (2008)
4. Hua, H., Liu, S.: Correct Focus Cues in Stereoscopic Displays Improve 3D Depth Perception. SPIE Newsroom (July 29, 2010), doi:10.1117/2.1201007.003109
5. Miyao, M., Ishihara, S., Saito, S., Kondo, T., Sakakibara, H., Toyoshima, H.: Visual Accommodation and Subject Performance During a Stereographic Object Task Using Liquid Crystal Sutters. Ergonomics 39(11), 1294–1309 (1996)
6. Hasegawa, S., Omori, M., Watanabe, T., Fujikake, K., Miyao, M.: Lens Accommodation to the Stereoscopic Vision on HMD. In: Shumaker, R. (ed.) VMR 2009. LNCS, vol. 5622, pp. 439–444. Springer, Heidelberg (2009)
7. Ishio, H., Sano, S., Shiomi, T., Kanda, T., Hori, H., Uemoto, K., Sugiyama, A., Niwa, M., Hasegawa, A., Matsunuma, S., Miyao, M.: Visibility Experiment and Evaluation of 3D Character Representation on Mobile Displays. In: Stephanidis, C. (ed.) Posters, Part II, HCII 2011. CCIS, vol. 174, pp. 46–51. Springer, Heidelberg (2011)
8. Shiomi, T., Hori, H., Uemoto, K., Miyao, M., Takada, H., Hasegawa, S., Omori, M., Watanabe, T., Ishio, H.: Comparison of Simultaneous Measurement of Lens Accommodation and Convergence in Natural Vision and 3D Vision. SID Symposium Digest of Technical Papers 43(1), 1178–1181 (2012)
9. Otake, Y., Miyao, M., Ishihara, S., Kashiwamata, M., Kondo, T., Sakakibara, H., Yamada, S.: An Experimental Study on the Objective Measurement of Accommodative Amplitude under Binocular and Natural Viewing Conditions. Tohoku Journal of Experimental Medicine 170(2), 93–102 (1993)