The effects of lens focus with varying stereoscopic depth cues on the eye fatigue level when viewing a binocular head-mounted display

K.M. Chang[1], Richard H.Y.So[1], H.C. Huang[2], Andrew Lam[3], Patrick Ting[3]

[1]Department of Industrial Engineering and Logistics Management, The Hong Kong University of Science and Technology, Hong Kong SAR

[2] Department of Electronic and Computer Engineering, The Hong Kong University of Science and Technology, Hong Kong SAR

[3] School of Optometry, The Hong Kong Polytechnic University, Hong Kong SAR

[1]ckman@ust.hk

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Abstract. People can suffer from eye fatigue and headache when viewing a stereoscopic binocular head-mounted display for a long period of time. One possible cause of eye fatigue is the mismatch between accommodation and vergence. For most binocular displays, the projected distance of images (i.e., lens focus) is fixed while viewers are usually required to view stereo images with varying stereoscopic depth cues. This posts an unnatural demand on human eyes as the eyes are forced to fix their accommodation while the vergence eye movements are dynamically changing according to the stereoscopic depth cues. This paper reports a study conducted to investigate the levels of eye tireness caused by viewing binocular display with lens focus matched or unmatched with the stereoscopic depth cues. Preliminary results are presented in this paper and the full results will be presented at the symposium.

Introduction

Background. When viewing a real object in the real world, our eyes will accommodate to focus at the object. At the same time, our eyes will also verge or turn inwards so that the line-of-sight of both eyes will point towards the object. Therefore, the vergence of eye will change in accordance or match with the accommodation of eye.

A binocular head-mounted display (HMD) usually consists of two screens with lens in front of the screens to present magnified images to both eyes, respectively. When both eyes see the left and right images from different perspective, the eyes will converge to fuse the two images into a single stereoscopic image with appropriate perceivable depth. HMDs are particular useful in applications where users need to interact with computer-generated objects (So and Griffin, 1991; So and Chung *et al.*, 1999). However, usability problems of time delays and motion sickness have been reported (Kiryu and So, 2007; Lo and So, 2001; So and Griffin, 1995; So and Lo, 1999; So and Finney *et al.*, 1999). In particular, when viewing a moving virtual object with varying depth using a binocular display, the eyes will accommodate to the fixed lens focus of the display to obtain clear images but vergence response has to dynamically be changing according to the changing stereo depth cues. This creates a mismatch between accommodation and vergence.

Research gap and hypothesis. The decoupling of accommodation and vergence when viewing stereoscopic display with varying virtual stereoscopic depth cues have been studied (Takeda et al. 1999), However, very few researches have studied the levels of eye fatigue caused by viewing

stereoscopic images presented in micro-displays. Yano *et al.* (2004) reported significant increases in levels of eye fatigue when viewing stereoscopic HDTV images. However, HMDs were not used and only one focal length was studied. This leaves a research gap in studying the levels of eye fatigue when viewing stereoscopic images presented on a HMD with matched and unmatched lens focus. In this study, two hypotheses are tested: H1: The levels of eye fatigue will increase when viewing images whose stereoscopic depth cues do not match with the lens focus. H2: The levels of eye fatigue will increase when viewing images projected at 40cm in front of the eyes than those images projected at 200cm in front of the eyes.

Experiment

Objectives. The objective of this experiment is to study the levels of eye fatigue when viewing stereoscopic images with matched and unmatched lens focus.

Design of Experiemnt. The independent variables are lens focus and stereoscopic depth cues. The lens focus has two levels: 40cm and 200cm. The stereoscopic depth cues also have two levels: stereo depth cues appropriate to a depth of 40cm ±0.3 dioptres and a depth of 200cm ±0.3 dioptres. The ±0.3 dioptres are within the normal range of depth of field (DOF).

The dependent variable is the rated levels of eye fatigue measured using a 7-point eye fatigue rating scale. Readings are taken every 2 minutes during the exposure.

The control variables are the randomized sequences of presentation of images with slightly different stereo depth and the time gap between the presentations of consecutive tasks. The experiment had four conditions: (i) lens focus was set at 40cm and stereo depth cues were appropriate to the depths of 40cm ± 0.3 dioptres; (ii) lens focus was set at 200cm and stereo depth cues were appropriate to the depths of 200cm ±0.3 dioptres; (iii) lens focus was set at 40cm and stereo depth cues were appropriate to the depths of 200cm ±0.3 dioptres; and (iv) lens focus was set at 200cm and stereo depth cues were appropriate to the depths of 40cm ±0.3 dioptres.

The experiment used a within-subject design and each subject took part in all four conditions in randomized order. At least 24 hours separation was given between each condition. Eight subjects took part in the experiment and the preliminary results of the first two subjects are presented in this paper. The full results will be presented at the conference. Both subjects had normal or corrected vision and they had been tested to have normal stereopsis ability and attained visual acuities of 20/20 or better.

The subjects were Chinese students or staffs at the university and the experiment has been approved by the Human Subject Committee of the Hong Kong Unievrsity of Science and Technology.

Methods and stimuli

Apparatus. A photograph of the HMD used in the experiment is shown in Figure 1.

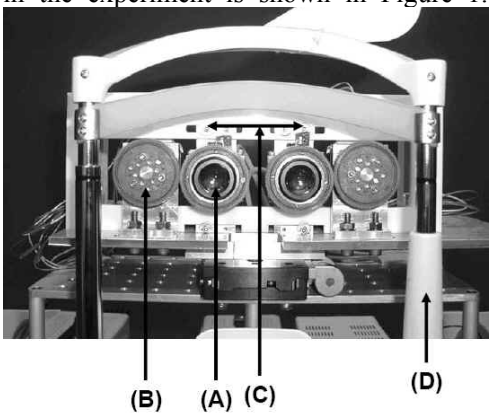

Figure 1. A photograph illustrating the HMD system. (A – lens for magnifying images on the LCD panels, B – motor with gear used to adjust the lens focus, C – the horizontal spacing between the two lens can be adjusted, D – the chin rest).

Stimuli. A sampled snap shot of the stereo images presented to the subjects' eyes are shown in Figure 2. It consists of five

Landoult C rings forming a cross shape. During the experiment, the stereo depth cues of the left and right pairs of landoult C rings would varied so that their depths would be appropriate to either 40cm ±0.3 dioptres or 200cm ±0.3 diphtres. The range of varying the depth is with the depth of field and is consistent with previous study (±0.3 dioptres, Yano et al. 2004). The virtual depths of the Landoult C rings would change after a random period of five to eight seconds and variation in depth (±0.3 dioptres) were also randomized to make the tasks less predictable. Subjects were required to read out the direction of the openings of the landoult C rings at the middle. Figure 3 shows the time history of the virtual depth of the stereo images during the first 100 seconds of the 30 minutes viewing tasks. The stereo images were generated using 3D Studio Max™.

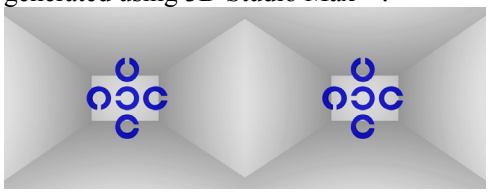

Figure 2. A snap shot of the stereoscopic image pair used in the experiment.

Procedure. During the experiment, the subjects were to rate their levels of eye fatigue according to a 7-point rating. These rated levels were taken every two minutes. During each condition, the subjects need to concentrate on the stereo images and verbally reported the direction of the openning of the Landoult C located at the middle of the cross pattern. Each condition lasted for 30 minutes and at least 24 hours separation was given before the subjects return another condition.

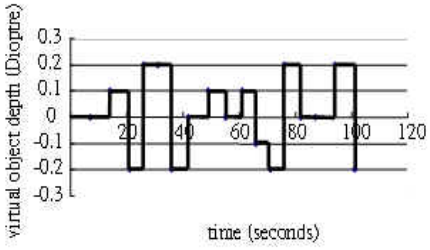

Figure 3. The time history of the depth of the stereo images during the first 100 seconds in each condition experiment.

Results

Figure 4 shows the average rated levels of eye fatigue as functions of the four conditions. The data were the mean of the two test subjects. The error bars indicate the ± standard deviation.

Discussions

Inspections of Figure 4 indicate that the rated levels of eye fatigues were the lowest at the viewing condition when lens focus was set at 200cm and the stereo depth cues were also set at 200cm ±0.3 dioptres. Because variations of 0.3 dioptres are within the depth of field, this viewing condition is consider to be one of the matched case in which the lens focus is appropriate to the stereo depth cue. Results of pair t-tests indicate that the rated levels of eye tireness in this matched condition was significantly smaller than those obtained in the corresponding unmatched condition (i.e., with lens focus equal to 200cm but the stereo depth cues were appropriate to 40cm ±0.3 dioptres) (p<0.001, paired t-test).

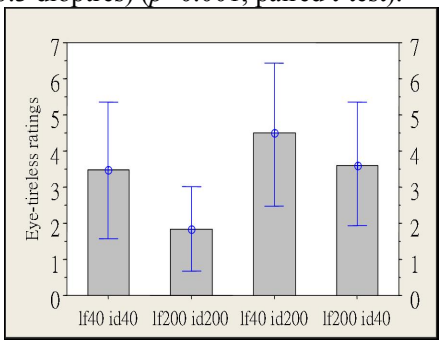

Figure 4. The averaged rated levels of eye fatigue from the first two subjects as functions of the four viewing conditions (NB: lf40: lens focus = 40cm, lf200: lens focus = 200cm, id40: stereo depth cues appropriate to depths of 40cm ±0.3 dioptres, id200: stereo depth cues appropriate to depths of 200cm ±0.3 dioptres).

When viewing images with stereo depth cues appropriate to depths of 40cm ±0.3 dioptres, using matched lens focus of 40cm and unmatched lens focus of 200cm resulted in no significant change in the rated level of eye fatigue (p>0.7, paired t-test). One possible reason may be due to the degrading effect of accommodation itself. Indeed, it has been found that the rated eye fatigue levels collected when viewing images with lens focus of 40cm are significantly higher than those collected when images with a lens focus of 200cm. (p<0.001, paired t-test).

Conclusions

From the preliminary result, it seems that matched lens focus with stereo depth cues can significantly reduce rated levels of eye fatigue (H1 supported). Also, lens focus also could affect the rated level of eye fatigue (H2 supported). Only preliminary data from the first two subjects are presented here, the conclusion will need to be confirmed with the full set of data.

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