Evaluation of Visual Fatigue and Sense of Presence for CAVE-like multi-projection display

Tetsuri Inoue\textsuperscript{a} and Takashi Shibata\textsuperscript{b}

\textsuperscript{a} Faculty of Information Technology, Kanagawa Institute of Technology, Atsugi, Kanagawa, JAPAN
\textsuperscript{b} School of Education, Tokyo University of Social Welfare, Isesaki, Gunma, JAPAN

We created a virtual-reality simulation of sea fish for science education and displayed it using a CAVE-like multi-projection display. Our intent with the display was to provide actual-size objects and produce stereoscopic 3D images of fish close to the observer, thus enhancing interactions with and understanding of the virtual fish. To examine the safety aspects and functional effects of the VR simulation with regard to observers, we conducted an experiment to evaluate observers’ visual fatigue and sense of presence while viewing the stereo images of fish located close to the observer in the CAVE-like display. The results of the visual fatigue evaluation showed that even for images with a large disparity, there was little ill effect from viewing the stereo images for a short duration. The results for sense of presence showed that the scores for questions about immersion in the virtual environment and concentration on the assigned tasks were highest while viewing stereo images located close to the observer in the CAVE-like display.

\textbf{Keywords}: CAVE-like display, stereo images, visual fatigue, sense of presence, education

1. Introduction

In recent years, rapid advances in computer and display technologies have enabled the presentation of high-quality virtual reality (VR) environments, which are computer-simulated environments. VR environments provide us with experiences that cannot be easily obtained in real-world situations, and they have been used in various fields such as medicine, engineering, design, training and education.

Education is an area in which VR environments can be effectively applied for teaching and learning. One example of VR application in education can be found in medical schools. VR technology can be used in surgical training simulators, or three-dimensional (3D) virtual models of the human body that students can explore (Zajtchuk & Satava, 1997). VR astronomy is another example of an educational application. Students can learn about the solar system using 3D display systems, they can move planets, look around stars, and track the progress of a comet in a virtual space simulator. Additionally, 3D virtual models have many advantages over traditional 2D images. For example, 3D models can be observed from different angles, whereas 2D images are limited to one view (Al-khalifah et al., 2006).

In this study, we created a VR simulation of sea fish for a science education program. The simulation provided a virtual undersea environment in which students could observe various types of 3D virtual fish models. We used a CAVE-like multi-projection display to present the VR simulation. The CAVE-like display is a room-sized visualization system in which screens surrounding the user produce a 3D virtual environment and deliver a sense of immersion (Cruz-Neira, Sandin, DeFanti, 1993). We expected the CAVE-like display to provide actual-size objects and produce stereoscopic 3D images of fish located close to the observer. The idea is that students can access and interact with the 3D virtual fish electronically to improve their understanding.

Virtual environments are of course different from real space, though recent VR technological advances have made it possible to present quite realistic virtual environments. The main issue is that the objects perceived by observers do not actually exist. We need to research how VR affects actual human observers if VR environments are to be effective and readily acceptable to users (Stanney et al., 1998).

To determine the visual safety and functional effects of VR simulation in relation to observers, we conducted an experiment to evaluate observers’ visual fatigue and sense of presence while viewing stereoscopic 3D images of fish located close to the observer in the CAVE-like display.
2. **VR Simulation of Sea Fish**

2.1 **CAVE-like Multi-projection System**

To present the educational VR simulation, we used a CAVE-like display system, specifically, a room-type multi-projection 3D display with four 2.5 m × 2.5 m screens (front, right, left, and floor), shown in Figure 1. Each screen was projected by two LCD projectors (SX-50, Canon) with 1024 pixels × 1024 pixels to display left and right images, generating a stereoscopic image. Observers wore circular polarizing filter glasses to view the stereoscopic 3D images, which were generated by eight personal computers synchronized to create the virtual environment scene. Images were generated and controlled by VR authoring software (Omega Space, Solidary Co., Ltd.).

![Figure 1. CAVE-like display system used for VR simulation.](image)

2.2 **VR Simulation of Sea Fish**

We created a VR simulation of sea fish for science education, with the objective of helping users learn the types of fish and the variety of fish habitats (Figure 2). The VR simulation was created and presented by the CAVE-like multi-projection system described above.

We chose this system for two reasons. First, it can display actual-size objects, which is considered important in education because the observer can compare the size of the object with his/her body (Kenyon et al., 2007). Second, the system can produce stereo images located close to the observer; thus, the 3D image is within the observer's reach. In contrast, conventional 3D displays generally cannot present stereo images with a high value of disparity that are sufficiently close to the observer.

![Figure 2. Example scenes of educational VR simulation of sea fish.](image)
3. Experiment

3.1 Visual fatigue and sense of presence in stereoscopic 3D

We evaluated observers' visual fatigue after they watched the VR simulation of sea fish. This was done because observers viewed stereo images with a large binocular disparity in the VR environment.

Stereoscopic 3D displays have a mismatch problem, in that they can produce a mismatch between the focus accommodation (focal distance) and the fixation (vergence distance) of human eyes. In stereo viewing on stereo display systems, the focal distance is fixed as the distance from the eyes to the display screen, while the vergence distance varies depending on the distance being simulated on the display (Figure 3). Thus, vergence–accommodation conflict is created by viewing stereo display systems. This conflict is one of the causes of visual fatigue and discomfort when looking at stereo images (Shibata et al., 2011 and Hoffman et al., 2008). In VR environments, observers often view stereo images with a large disparity to be immersed in the realistic environment with actual-size objects and stereo images close to the observer. Therefore, considering visual fatigue during use of VR simulations is very important.

![Diagram of stereo viewing on stereo 3D displays.](image)

Figure 3. Diagram of stereo viewing on stereo 3D displays.

We also evaluated observers' sense of presence while watching the VR simulation. The objective of the evaluation was to determine whether the VR environment surrounding the user and the 3D images of sea fish located close to the observer could enhance the observer's perception of being present in a virtual environment.

3.2 Experimental images and viewing conditions

The object viewed as a visual target contained five types of fish extracted from the VR simulation. Each fish was 14 cm long. The background scene was the ocean floor. The distance from the participant to the front screen was 200 cm. The images of the fish were presented in a pseudorandom order, normally facing to the left but sometimes to the right. The task for the participant was to identify the fish facing to the right and then push a button. Each object presentation lasted 5 s, and the presentation had a total viewing time of 5 min.

Participants viewed the stereo images in the CAVE-like display under three experimental conditions (Table 1). A stereo image with 5° of binocular disparity was displayed in condition 1; the image was represented at 54 cm from the observers. The disparity was determined on the basis of our previous study, which suggested the most appropriate position for use of the VR simulation from the viewpoint of size estimation. In condition 2, a stereo image with 1° of binocular disparity was displayed; 1° of binocular disparity for stereo images is regarded as safe for stereoscopic 3D content. We used this condition to compare the degree of visual fatigue. In condition 3, a stereo image with 5° of binocular disparity was displayed, similar to condition 1; however, the view range was clipped. Also, a part of the image was...
presented on the front screen of the multi-projection system to simulate television viewing. The viewing angle of the simulated screen was 33°; so observers viewed it from a distance three times as long as the simulated screen height. The order of viewing conditions was randomized.

Table 1. Experimental viewing conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Screen type</th>
<th>Binocular disparity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Multi-projection</td>
<td>5°</td>
</tr>
<tr>
<td>2</td>
<td>Multi-projection</td>
<td>1°</td>
</tr>
<tr>
<td>3</td>
<td>Simulated TV</td>
<td>5°</td>
</tr>
</tbody>
</table>

Figure 3. Masked images of front screen under condition 3.

3.3 Questionnaires

All participants completed two types of questionnaire during the experiment. The first questionnaire dealt with visual fatigue and discomfort (Table 2). Participants rated their symptoms on a 7-point Likert scale, where 1 indicated no negative symptoms of tiredness and 7 indicated severe symptoms. There were ten questions in total. Subjective symptoms were measured four times for each experimental condition: before viewing the 5-min stimuli (pre), immediately after viewing (post 1), 5 min after viewing (post 2), and 10 min after viewing (post 3).

Table 2. Questionnaire on symptoms related to visual fatigue and discomfort.

<table>
<thead>
<tr>
<th>Eye strain</th>
<th>Headache</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye ache</td>
<td>Pain in the temple</td>
</tr>
<tr>
<td>Dry eyed</td>
<td>Pain in the middle of forehead</td>
</tr>
<tr>
<td>Far vision difficulty</td>
<td>Nausea</td>
</tr>
<tr>
<td>Near vision difficulty</td>
<td>Feeling of weariness</td>
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</table>
The second questionnaire dealt with the sense of presence (Table 3). Participants rated their responses on a 7-point Likert scale after viewing the 5-min stimuli. This questionnaire was based on Witmer and Singer’s Presence Questionnaire (Witmer & Singer, 1998). Participants answered a total of eight questions relating to sense of presence.

Table 3. Questionnaire on sense of presence

<table>
<thead>
<tr>
<th>Question</th>
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<tbody>
<tr>
<td>(1) How much did your experiences in the virtual environment seem consistent with your real-world experiences?</td>
</tr>
<tr>
<td>(2) How closely were you able to examine objects (3D fish)?</td>
</tr>
<tr>
<td>(3) To what degree did you feel confused or disoriented at the end of the experimental session?</td>
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<tr>
<td>(4) How involved were you in the virtual environment experience?</td>
</tr>
<tr>
<td>(5) How much did the visual display quality interfere or distract you from performing assigned tasks?</td>
</tr>
<tr>
<td>(6) How well could you concentrate on the assigned tasks or required activities?</td>
</tr>
<tr>
<td>(7) Were you involved in the experimental task to the extent that you lost track of time?</td>
</tr>
<tr>
<td>(8) How much easily did you watch the 3D models of fish?</td>
</tr>
</tbody>
</table>

3.4 Procedure and subjects

Participants were required to wear 3D glasses (circular polarizing filter glasses) and to view the stereo images in the CAVE-like display under one of the three experimental conditions listed in Table 1.

The experiment was carried out as follows:

1) Evaluation of visual fatigue (pre)
2) Presentation of stereoscopic images (5 min)
3) Evaluation of visual fatigue and sense of presence (post 1)
4) Five-minute break (including the evaluations in no. 3 above)
5) Evaluation of visual fatigue (post 2)
6) Five-minute break (including the evaluations in no. 5 above)
7) Evaluation of visual fatigue (post 3)
8) Interview

Participants were required to repeat the procedure under each experimental conditions including a rest of at least half an hour.

Twenty-one participants ranging in age from 21 to 24 years, took part in the experiment. All had normal stereo-acuity according to the Titmus stereo test, and those who normally wore corrective lenses wore them during the experiment. None of participants were aware of the experimental hypotheses.

4. Results

For visual fatigue and discomfort, under all conditions, there was a tendency for the degree of symptoms to increase immediately after viewing. However, overall intensity of symptoms was quite low, and there were no significant differences among the experiment conditions for all symptoms. Here, we focus on the symptoms of visual fatigue because these symptoms showed the highest rate of change before and immediately after image viewing under all experimental conditions. Figure 4 shows the results obtained from the symptoms questionnaire, averaged across participants. The ordinate represents the reported severity of symptoms from 1 to 7, where 7 is the most severe. Although all scores were relatively low, there was a tendency for the degree of visual fatigue to increase immediately after each viewing (post 1); however, the intensity was reduced with time.

For the sense of presence, the average scores under condition 1 (multi-projection, 5°) were higher than under the other conditions, except for the question about perceiving the stereo image as being located close to the observer. The scores for the questions about immersion in the virtual environment (Figure 5) and concentration on the assigned tasks (Figure 6) were highest under condition 1 (statistically significant, p < 0.05 and p < 0.01, respectively). As for the question about immersion in the virtual environment, a significant
difference was observed between conditions 1 and 3 ($p < 0.01$). For the question about concentration on the assigned tasks, significant differences were present between conditions 1 and 2 ($p < 0.05$) and conditions 1 and 3 ($p < 0.01$).

Figure 4. Results of visual fatigue (eye strain) from the symptoms questionnaire.

Figure 5. Results for immersion in virtual environment from presence questionnaire.

Figure 6. Results for immersion in virtual environment from presence questionnaire.
5. Discussion and Conclusion

We created a VR simulation of sea fish for science education and conducted an experiment using the simulation. We chose a CAVE-like multi-projection display for presenting the educational VR simulation because this type of display can provide actual-size objects and produce stereo images close to the observer.

In the experiment, we examined the safety aspects and functional effects of viewing the VR simulation. The results of visual fatigue showed that all symptom scores were relatively low. There was a tendency for the degree of visual fatigue to increase immediately after each viewing, but the intensity of these symptoms reduced with time. In general, stereo images with 5° of binocular disparity create excessive vergence–accommodation conflict, causing observers to feel severe visual fatigue in prolonged stereo viewing. However, our finding showed that viewing stereo images with 5° of binocular disparity was not a serious problem from a safety viewpoint over a short 5-min viewing time. Additionally, there is generally an advantage to using VR simulations over viewing stereoscopic 3D movies in that observers can control the position of an object in the VR environment, which means they can choose a comfortable stereo image position if they feel some discomfort.

The results for sense of presence showed that the scores of questions about immersion in the virtual environment and concentration on the assigned tasks were highest when viewing stereo images with 5° of binocular disparity in a multi-projection condition.

The findings in this study demonstrate that the CAVE-like multi-projection display can provide 3D models located close to the observer with the same level of visual load as that located distant from the observer and can enhance the sense of presence more effectively than conventional single-screen displays. We conclude that the VR simulations provided by the CAVE-like display can be effective and comfortable for educational application.

As future work, we need to examine 3D images with motion in the CAVE-like display. In this study, we used static 3D models as stimulus. 3D images containing moving objects could lead to visually induced self-motion perception and cause motion sickness (Hettinge 2002). We thus need to investigate the visual load and sense of presence of the CAVE-like display by using a different evaluation method such as the Simulator Sickness Questionnaire. Another future task is to investigate the educational effects of VR simulations compared with conventional educational materials.

Acknowledgements

This research was partially supported by the Nakajima Foundation and Japan Society for the Promotion of Science (25560118). The authors also thank Jae-Lin Lee for help in running the experiment.

References


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