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The effect of parallax on eye fixation parameter in projection-based stereoscopic displays

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ABSTRACT

The promising technology of stereoscopic displays is interesting to explore because 3D virtual applications are widely known. Thus, this study investigated the effect of parallax on eye fixation in stereoscopic displays. The experiment was conducted in three different levels of parallax, in which virtual balls were projected at the screen, at 20 cm and 50 cm in front the screen. The two important findings of this study are that parallax has significant effects on fixation duration, time to first fixation, number of fixations, and accuracy. The participant had more accurate fixations, fewer fixations, shorter fixation durations, and shorter times to first fixation when the virtual ball was projected at the screen than when it was projected at the other two levels of parallax.

1. Introduction

Nowadays, virtual reality (VR) is becoming widely popular, and the promising technology of VR has been applied in training for laparoscopic surgery (Hart and Karthigasu, 2007), virtual rehabilitation therapy (Burdea, 2002), balance exercise programmes for traumatic brain injury (Thornton et al., 2005), training for autistic spectrum disorder (Parsons and Mitchell, 2002), training in the automotive industry (Lawson et al., 2016), manufacturing process simulations (Mujber et al., 2004), wheelchair driving simulator (Alshaer et al., 2017) and education (Bell and Fogler, 1995). A VR system provides interactive computer graphics that allow users to experience personal 3D viewing and interact with objects in a virtual environment (VE) (Czernuszenko et al., 1997; Sharples et al., 2008). The hardware devices required to achieve a 3D VE include a computer, a device display, and a handheld input device (Lin et al., 2015a). In the early 1990s, the head mounted display (HMD) was the leading device display screen that allowed users to experience an immersive presence in VEs (Sharples et al., 2008). Moreover, users can have their own personal displays to interact and experience virtual targets because an HMD can effectively block out the real environment (Mcneill et al., 2004). However, HMDs have some limitations and can be invasive to users. HMDs are worn on the head, and the weight is carried by the neck (Czernuszenko et al., 1997). This weight can cause modification of neck posture and increase stress on the musculoskeletal system of the head and neck (Mon-williams et al., 1995). Moreover, users who wear an HMD may experience symptoms of nausea, dizziness, vomiting, and visual problems (Mon-williams et al., 1995; Knight and Baber, 2007). To provide a wide field of view, HMDs require non-linear optic, which cause distortion (Czernuszenko et al., 1997). Furthermore, HMDs allow users to perceive virtual objects in positive and zero parallax as most close to user's eyes (Zhou et al., 2008).

As another option, a projection-based system in VR has been developed in recent years. Projection-based VR uses wide, large, multi-touch, tracked hand-held display, and a fixed screen display in a relative distance from the user (Benko et al., 2004). Such a projection system provides several advantages. First, it allows for multiple users to share and communicate with each other about the 3D environment by wearing 3D glasses (Sharples et al., 2008). Second, a projection-based system can minimize the stress on the musculoskeletal system because users simply wear lightweight (3.3 oz) 3D glasses (Czernuszenko et al., 1997). In that condition, users can comfortably view 3D images and interact with the virtual environment. Projection display also produces a satisfying interaction feeling of augmentation in augmented reality (AR) (Zhou et al., 2008). AR systems incorporate real and virtual objects in a real time (Azuma et al., 2001). In a projection system, a virtual object appears in negative parallax (in front of the projection plane) and positive parallax (Petkov, 2012); therefore, a user can obtain satisfactory depth perception and interaction with virtual objects. However, such a system also has drawbacks; a projection system lacks mobility because the set up of projection stay in fixed position (Zhou et al., 2008), and it cannot rotate the whole virtual world when the user rotates his or her head (Lin et al., 2015a).

In this study, we used projection-based stereoscopic 3D displays. The stereoscopic 3D display is one technique for enhancing the illusion of depth in an image. The principle behind generating 3D images

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requires the control of parameters, especially parallax. Parallax is the horizontal display disparity of two images between the left and right eyes to create 3D images (Smith et al., 2012; Lang et al., 2010). The eyes' axes of vision cross at the particular point where the virtual object is located, and the convergence of the eyes creates an illusion of depth (Seigle, 2009). Human perception requires the left and right eye to see difference perspective images in the same scene (Valkov et al., 2011). To perceive 3D image, with the left and right images providing information, the brain must be able to integrate the depths from the projection of two images into a single three-dimensional object (Lebreton et al., 2012). Parallax and depth perception have important rules for creating 3D images in a virtual environment.

However, the binocular depth perception relation in stereoscopic displays may cause visual problems, and parallax might be the underlying cause. The problems may be visual discomfort (Lambooij et al., 2009), asthenopia or eye without strength (Mackenzie, 1843), eyestrain (Council, 1983), accommodation and vergence mismatch (Emoto et al., 2005; Hoffman et al., 2008; Wann et al., 1995; Okada et al., 2006). Moreover, parallax may also caused inaccuracy of distance judgment (Lin et al., 2015b; Lin and Woldegiorgis, 2017). Therefore, it is worthwhile to investigate the effects of parallax in a virtual environment.

Investigation of the effects of parallax requires discovery of the eye parameters in stereoscopic displays. Eye tracking technology is powerful device for investigating the effects of parallax and depth perception because eye movement data provide evidence of visual attention as fundamental system in visual perception (Von Helmholz, 1897). Recording eye movement data can allow detection of the visual attention path of a participant, and then it can be derived that the human perceived the object (Duchowski, 2007). Eye tracking technology captures what the user is looking at. Eye tracking detects and tracks the movement of the eyes and records the eye points and gaze points. In eye tracking analysis, an algorithm is used to classify data as eye fixation data or saccade (Shic et al., 2008). The application of eye tracking technology allows our eyes to control a device as naturally as the movement of our eyes, so eye tracking technology has been used in many disciplines of research, such as measuring software screen complexity (Goldberg, 2014), web page viewing behaviour (Pan et al., 2004), eye pointing performance (Lin and Widyaningrum, 2016), market research and advertising testing, eye control for accessibility, psychology and vision research, medical research, diagnostics and rehabilitation, and gaze interaction and car assistant systems (Drewes, 2010). Hence, it is very helpful to visualize a participant's eye movement with eye tracking technology (Deutsch and Deutsch, 1963).

In eye tracker data, eye fixation data are the fundamental data used to evaluate eye performance and behaviour. Eye fixation is fascinating to explore because a cognitive process allows the viewer to see something interesting in the eye fixation process (Blignaut, 2009). The oculomotor definition of eye fixation is that the eyes remain in the current position (Holmqvist et al., 2011). A previous study examined the eye fixations of users in accomplishing a task and identified the number, position, and duration of fixations in screen displays. The study was conducted to measure eye fixation (number, number per line, rate, duration, and words per fixation) as a function of character and line spacing in a reading task (Kolers et al., 1981). The result showed that more fixations per line and fewer fixations per word were associated with more tightly-grouped, singled-spaced material. Goldberg and Kotval (1999) presented an introduction and a framework of eye movement analysis techniques. That study recruited 12 subjects to experience good and poor software interfaces and measured the number of fixations, fixation duration, fixation/saccade ratio, and other measurements. The number of fixations is related to the number of components that the user is required to process to select the target. Participants made more fixations when they experienced bad interface design. Furthermore, fixation duration was required by the participants to interpret or relate the components represented in the interface. The duration of a single fixation on targets was dependent on the interface layout. Goldberg (2014) conducted a study to measure the complexity of software screens by relating eye tracking, emotional valence, and subjective ratings. In that study, participants were asked to complete 25 tasks on screen pages designed with various combinations of page category, gradient, font, and font size combination. The results showed that participants' time to first fixation was longer when the larger fonts required searching a larger search area, and longer completion times caused a greater number of fixations. Therefore, longer fixation durations were associated with confusion or difficulty in processing tasks. Those studies showed that eye fixation was associated with efficiency in performance. Eye fixation is important to engineers designing effective displays to improve usability issue.

However, as explained above, most of the literature about eye fixation has been conducted using 2D or screen displays. The analysis of eye fixation has not considered depth perception in accomplishing a task. Therefore, in this study, we investigated the effect of parallax on eye fixation parameter, especially number of fixations, time to first fixation, fixation duration, and accuracy in stereoscopic displays. We predicted that the fixation duration, number of fixations, time to first fixation, and accuracy would be affected by parallax due to the limitations of the eyes in a 3D visual environment.

2. Methods

The aim of this study was to investigate the effects of parallax on eye fixation in projection-based stereoscopic displays. Participants were asked to perform a pointing task in which a mouse with a 3D cursor and their eyes were used to point to a concentric circle of virtual balls. An eye tracker recorded the eye movements and eye fixations of the participants as they used hand movements to move the 3D cursor to point to the virtual ball. In this study, three different levels of parallax was used to examine the differences in depth perception of a 3D virtual ball projected level with the screen (at the screen), 20 cm in front of the screen, or 50 cm in front of the screen. The participants accomplished the trials in randomized order for each level of parallax.

2.1. Participants

Ten graduate students at National Taiwan University of Science and Technology participated in this study. Their mean age was 25 years with a standard deviation of four. All participants had normal or corrected to normal visual acuity (1.0 in decimal units). The participants were volunteers and were not given any compensation for performing the stereoscopic task. The study was approved by the ethical guidelines of the Research Ethics Committee of National Taiwan University. Participants completed consent forms before performing the task.

2.2. Apparatus and tools

The Tobii X2-60 eye tracking system, which has a 60 Hz sampling rate, was used to record the movements of participants' eyes. An I-VT fixation filter was used to filter out the raw eye movement data with a 30°/second velocity threshold (Salvucci and Goldberg, 2000). The fixation filter Tobii Studio version 3.3.2 software was used for calibration, testing, and data analysis. Eye movement data were exported for further data processing and statistical analysis. To perceive the stereoscopic 3D environment, the participant wore a pair of ViewSonic 3D glasses (PDF-250) integrated with a 3D vision IR Emitter from NVIDIA and a 3D ViewSonic (PJD6251) projector. The projection screen was 143 cm × 108 cm. The virtual ball was drawn using the Unity 3D platform (version 4.3.4) run on an Asus Windows Core i5 personal computer. A Logitech C-920 webcam integrated with Tobii studio was used to record the eye movement data from the screen display.

An illustration of the experimental layout is presented in Fig. 1. The