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Ergonomic evaluation of interaction techniques and 3D menus for the practical design of 3D stereoscopic displays

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ABSTRACT

There has been a recent commercialization of 3D stereoscopic displays in order to implement them in a virtual reality environment. However, there is a lack of extensive research into user interfaces for 3D applications on stereoscopic display. This study focused on three representative interaction techniques (ray-casting, keypad and hand-motion techniques) utilizing a head-mounted display and 3D CAVE. In addition, the compatibility with 3D menus was also investigated based on performance and subjective assessment. Nine 3D menus were designed for the experiment in regards to three 2D metaphors (pop-up, pull-down and stack menus) and three structural layouts (list, cubic and circular menus). The most suitable technique for the 3D user interface on a stereoscopic display was the ray-casting technique and the stack menu which provided the user with good performance and subjective response. In addition, it was found that the cubic menu was not as effective as other menus when used with the three interaction techniques.

Relevance to industry: This research describes a distinctive evaluation method and recommendations that guarantee the suitability for interactive 3D environments. Therefore, the results will encourage practitioners and researchers that are new to the area of 3D interface design.

1. Introduction

Through the development of 3D stereoscopic displays (SD) by the television or mobile industry, users are becoming more acquainted with the use and convenience of 3D applications (Datcu et al., 2015; Lin et al., 2015b; Read, 2014). For example, users are able to enjoy 3D applications through the adoption of glasses rather than the use of heavy equipment such as head mounted display (HMD) or 3D CAVE. As SD is being popularized, manufacturers are trying to develop innovative user interfaces for 3D applications implemented for SD. To design a new user interface (UI), they often consider adaptability for new technologies rather than user aspects which results in a lack of user evaluation for the interaction and navigation method (Bowman et al., 2006; Li et al., 2015; Mun et al., 2013).

3D TV could provide a dramatic improvement in the viewing experience as seen in Fig. 1(c). However, although hardware characteristics of 3D SD have continuously progressed, representation and interaction techniques for stereoscopic contents remain inadequate for the human visual system. One of the primary potential side-effects such as visual and cognitive fatigue or blurred vision can occur when viewing 3D SD (Park et al., 2015; Pölönen et al., 2013; Read and Bohr, 2014; Ukai and Howarth, 2008; Zeri and Livi, 2015). Furthermore, a lack of consensus on interaction standards has impeded appropriate perception and response for viewers of 3D SD. Therefore, more efforts and relevant research on viewing comfort and interaction design of SD are required to enhance the adaptability of the technology for users.

For the traditional virtual reality environment (VRE), HMD allows the user to experience a seamless real-world view illustrated in Fig. 1(a). 3D CAVE is a large theater sited within a room. The user wears stereoscopic shutter glasses inside the CAVE to see 3D applications as depicted in Fig. 1(b). Since HMD and 3D CAVE can simulate a physical environment similar to the real world, it is difficult for the user to distinguish the boundary between VR and the real world in terms of their visual field. While HMD and 3D CAVE covers the entire visual field, SD allows the virtual 3D image to be shown only from the frontal visual field of the user.

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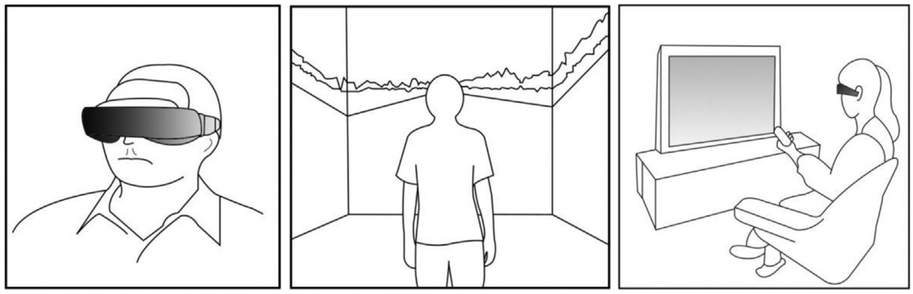

Fig. 1. Types of 3D applications under virtual reality environment.

Furthermore in SD, the view of virtual 3D image is fixed even if the distance between the user and the image differs. This may result in difficulties for enlarging and rotating virtual items or objects. Therefore, the performance and subjective response of previous interaction techniques and 3D menus that were originally developed for HMD and 3D CAVE should be further investigated to be properly applied to SD.

Although numerous 3D UIs have been proposed, there has yet to be a discovery for a universal interaction technique, such as the mouse and keyboard in 2D, for users to interact with 3D interfaces (Hickey et al., 2012; Muller et al., 2010; Taha et al., 2014). Even if the user experiences an identical 3D UI under different VREs, there are differences in performance and subjective ratings. The objective of this study is to investigate potential interaction techniques and 3D menus that would allow for efficient and convenient 3D menu navigations for SD. In addition, we discuss and propose important ergonomic recommendations for 3D UI designers. The results of this study contribute to new interface designs that are better suited for user's performance and satisfaction.

1.1. Interaction techniques

Interaction techniques provide the user with the means to execute different types of tasks in VRE. Bowman and Hodges (1999) proposed three basic interaction tasks: viewpoint motion control, selection and manipulation. This previous study focused on the selection task because the user performs this task more frequently than other tasks when interacting with 3D menus. A specific interaction technique could result in better performance for a certain task such as selection. However, the same interaction technique could induce discomfort for a different task such as manipulation. Since our study investigated the compatibility between interaction techniques and 3D menus, interaction techniques developed for the selection of 3D menu in the field of VR were reviewed.

Liang and Green (1993) proposed a ray-casting technique that was called a “laser gun” selection. This technique was designed in a such way that the ray is emitted from the user's hand. Therefore, the user controls a cursor like physical laser pointer. However, it was found to be difficult to select an item in an occluded and dense environment (Vanacken et al., 2009). A more direct method of interaction is mapping the user's hand motion to a 3D cursor (Poupyrev et al., 1996). The hand-motion technique is more intuitive and cognitively simple, but it is known to be inappropriate for manipulation tasks (Bowman et al., 1999; Choi et al., 2014; Rempel et al., 2014).

Several studies compare the advantages and disadvantages of two interaction techniques in HMD. Bowman et al. (1999) reported that the ray-casting technique yields a significantly shorter completion time than the hand-motion technique for target selection. On the other hand, Dubois et al. (2005) showed that the hand-motion technique required a shorter selection time than the ray-casting technique during side-to-side and in-depth movements. Bowman et al. (2007) evaluated these two interaction techniques for HMD and 3D CAVE. They concluded that the performance of the interaction techniques was considerably affected by VRE.

To summarize our review on interaction techniques, there are three candidates for the technique, which are suitable for the selection task in SD environments: the ray-casting, hand-motion and modified 2D interaction techniques. However, previous research focused mainly on developing and evaluating input devices without considering their compatibility with 3D menus.

1.2. 3D menus

A menu is a basic term used to describe an interface for the user to navigate through items and select a target item. Meanwhile, SD provides a virtual 3D space in which 2D menus are replaced by 3D counterparts. Since more space becomes available to display menus, the presentation method and selection process of menus would be more varied than those of 2D environment (Mine, 1995; Steinicke, 2007).

The metaphor of 2D menus has long been applied to 3D menu design. Jacoby and Ellis (1993) proposed improved pop-up and pull-down menus for VRE. Bowman and Wingrave (2001) designed a 3D floating menu which acts like the pull-down menu in a 2D display. Kim et al. (2000) reclassified several 2D and 3D menu presentation types in VRE and evaluated five 3D menus: pull-down, pop-up, stack, object-specific, and oblique/layered menus. They discovered that the stack menu showed the best performance among the five menus in HMD. The stack menu persistently displayed a selection path and could be re-selected to jump through previously visited menu items. Gerber and Bechmann (2005) evaluated three hierarchical 3D menus: crossed, concentric and stacked menus. These layouts were designed based on the concept of the circular menu. The results of the evaluation revealed that the stacked menu was the most efficient menu among the three layouts.

These previous studies showed that the 2D metaphor might still be applied to 3D menu design. Still, there are complications that may occur in application. For instance, there is no consideration for depth in a 2D metaphor. Since a 3D menu design works in a floating 3D space, there may be multiple depths and different viewing angles for the 3D menu, which results in altering the arrangement of the 2D metaphor which then affects performance and subjective response of interaction techniques.

Dachselt and Hubner (2007) surveyed existing 3D menus and