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Kinematic analysis of direct pointing in projection-based stereoscopic environments

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ABSTRACT

This work investigated the effects of visual information, parallax, and target positions on movement performances in projection-based stereoscopic displays (PSDs). Fifteen (26.5 ± 3.83 years) self-declared right-handed individuals, with normal or corrected to normal visual acuity, completed pointing tasks in stereoscopic and real environments (RE). Three-dimensional spatial data, recorded by a motion system composed of six infrared cameras, was used to compute kinematics of reaching a real/virtual object at a combination of three parallax and nine frontal planar positions. The results indicated that movement in the PSD was slower and needed longer confirmation time than that in the RE. This might be because of the difficulty and misperception of distance associated with PSD. The motions were initiated faster but took longer to complete in vision-based conditions. The overall kinematic parameters were better as targets were presented closer to participants and around the center of displays. However, during pointing at a target that was continuously visible or presented briefly and disappeared, participants applied similar movement strategies to approach the visual objects. The comparable kinematics and movement behaviors in stereoscopic displays encourage the use of direct pointing that would enhance reaching and grasping tasks – which are important in applications such as rehabilitation, surgical training, and other programs that employ upper limbs. In addition, the more natural interaction by direct pointing minimizes the effort of learning new skills to use other devices.

1. Introduction

The past three years brought a new momentum of virtual reality (VR) technology as many new products are becoming more accessible and affordable to the public than ever before. The competition among manufacturers is interesting to follow with Vive of HTC, Oculus Rift of Facebook, PlayStation VR of Sony, and Gear VR of Samsung. New products are still emerging from various other sources such as Google (Daydream View and Google Cardboard), Microsoft (Microsoft HoloLens), Meta 2, Razer's OSVR, FOVE VR, and Zeiss VR One Plus. The dimensions of the competition varied with respect to quality, price, customers, etc. Some manufacturers focus on delivering the highest level of reality, while others look for a less expensive product for mass users. Moreover, a few others attempted to address the needs of developers. A majority of the new VR sets are smartphone based as compared to those that deal with PCs and gaming consoles. Gaming and entertainment being at the center of the development, the interaction mechanisms also emphasize on delivering maximum possibility of playing and/or watching features. However, applications such as motor skill training, medical surgeries, and navigations that demand more precise interactions and accurate spatial information, might need to

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wait until the technology matures (Achibet, Girard, Talvas, Marchal, & Lécuyer, 2015; John et al., 2015; Saiano et al., 2015). The trend presented interesting challenges and new questions to human-computer interactions. So far the literature supported the advantages of stereoscopic viewing over 2D and perspective 3D (McIntire, Havig, & Geiselman, 2012), with all its difficulties in spatial manipulations, searching, planning, learning, and judgment of positions.

Cursors are commonly used in a computer-based interaction to provide a real-time visual feedback of hand position while performing a task. As a matured interaction technique, various improvements have been made to enhance handheld cursor-based devices. Different scenarios of input-output can be considered for interactions with stereoscopic 3D displays. Using 3D controls for 2D displays might have different performance as compared to when both control and display are in two-dimensional (Lee, Wu, & Liu, 2013). However, these traditional devices (such as mouse and trackballs) lack their dominance in three-dimensional computer simulated environments because of their limitations such as depth parameters. Stereoscopic and three-dimensional interactions could not entertain the advantages of the many years of research on the traditional input devices. On the other hand, because of the advances in tracking and camera technology, various interaction techniques are emerging (Achibet et al., 2015; Erazo & Pino, 2015; Nguyen & Banic, 2015; Youngkyoon, Seung-Tak, Hyung Jin, Tae-Kyun, & Woontack, 2015). Using avatars to improve the movement quality repeatability of motions, direct interaction led to execute tasks faster and reach more accurately (Camporesi & Kallmann, 2016). Furthermore, more direct and natural pointing techniques that employ users hand without carrying any device could be a very important supplement to the VR technology. Among noteworthy recent efforts, Achibet et al. (2015) proposed elastic arm armature connecting fingers to shoulder, and provide egocentric passive haptic feedback. The authors suggested that the device was not only cost effective and simple but also enhance perception. Claimed to be more universal, self-contained, and mobile, wearable input device was designed by Nguyen and Banic (2015) to ensure improved accuracy and less fatigue. These attempts will have a positive impact on the prospect of realizing bare-hand interactions with 3D objects, as shown in an exemplary experiment of Youngkyoon et al. (2015).

A speed/accuracy tradeoff in 2D and 3D interactions has been modeled, being affected by the movement distance and size of targets, and expressed in terms of an index of difficulties (IDs). Later, different other factors such as control-display (CD) gain have been studied to impact performances. Similar to the speed/accuracy tradeoff, some studies attempted to explain the characteristics of movement by its shape (usually, velocity profiles). Meyer, Abrams, Kornblum, Wright, and Smith (1988) proposed a stochastic optimized sub-movement model for Fitts' law (Fitts, 1954; MacKenzie, 1992; Soukoreff & MacKenzie, 2004) that involves a primary sub-movement and optional corrective secondary sub-movement by using a parsing method of movement sequences that are defined by parameters in the velocity profiles. Optional secondary sub-movement has been assumed since it entirely depend on the effectiveness of the first phase. If the first movement succeed to hit the target, no update or correction would be required. On the other hand, if the visual feedback results in a failed attempt, the secondary sub-movement follows. Based on Fitts' law assumptions, each sub-movement is completed at a constant proportion of the remaining distance to the center of the target. The assumption, however, was challenged by Meyer et al. (1988) for the constancy of movement proportionality, especially for the secondary sub-movement phase. For interactions involving mouse, entire movement was divided into four (Thompson, McConnell, Slocum, & Bohan, 2007; Walker, Meyer, & Smelcer, 1993) components; initiation (reaction phase), primary sub-movement phase, secondary sub-movement phase (where applicable), and confirmation (verification or correction phase). This classification has been adopted to three dimensional perspective viewing environment in Lee et al. (2013).

Previous studies investigated movement related issues and factors that influence interactions in 2D (Thompson et al., 2007) and 3D perspective environments (Lee et al., 2013). Thompson et al. (2007), classified the speed/accuracy tradeoff factors as effector or task related. The results showed that the movement distance was an effector constraint, target size was a task constraint, and movement orientation demonstrated both effector and task constraint characteristics. Similarly, Lee et al. (2013) created a touchless free-hand pseudo-3D environment to study the behavior of pointing and hand movements. They identified two types of motion behaviors adopted by users of natural hand movements to navigate in a 3D environment; straight line and sequential movement strategies. However, pointing kinematics and the patterns depicted by velocity plots are missing in the stereoscopic displays literature. Among the limited number of related studies, Teather and Stuerzlinger (2011) investigated desktop based stereo head tracked VE to compare task execution of different pointing techniques based on movement time. Likewise, Piromchai, Avery, Laopaiboon, Kennedy, and O'Leary (2015) attempted to evaluate the prospect of using VE in surgical training by comparing it to the reaching attainment of a real world, and based on the result of movement time, they concluded that it could be used as supplement to a physical training. Furthermore, Levin, Magdalon, Michaelsen, and Quevedo (2015) evaluated the effect of reaching with haptic feedback and observed similar movement strategy but slower and less smooth reaches in an HMD-based virtual environment than in a physical world. Regardless of its importance, because of the recent breakthrough in the VR technology, performance and movement behaviors in stereoscopic displays are not sufficiently studied especially when relatively direct pointing techniques were used to approach virtual objects.

In projection based stereoscopic displays, parallax which can be set by separating the distance between the two images for right eye (invisible to the left eye) and left eye (invisible to the right eye) and subsequently determine the position of the virtual target with respect to the projection screen, was proved to be important factor affecting the perception of distance in both exocentric (Lin, Woldegiorgis, & Caesaron, 2014; Lin, Woldegiorgis, Caesaron, & Cheng, 2015) and egocentric (Bruder, Argelaguet, Olivier, & Lécuyer, 2016; Lin, Ho, & Chen, 2015) space. Generally, distance was over- and under-estimated, respectively, in negative and positive parallax (Bruder et al., 2016; Bruder, Sanz, Olivier, & Lecuyer, 2015), where the smoother movement was observed in the negative and zero parallax (Lin, Ho, et al., 2015). Furthermore, Lin and Woldegiorgis (2015) and Renner, Velichkovsky, and Helmert (2013) summarized the results of previous studies on spatial perception and accuracy of distance estimations in virtual environments found that the judgment suffered with increase in distance. Especially, when pointing tasks were adopted, relatively accurate