Development and Evaluation of a Hands-Free Motion Cueing Interface for Ground-Based Navigation

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ABSTRACT

With affordable high performance VR displays becoming commonplace, users are becoming increasingly aware of the need for well-designed locomotion interfaces that support these displays. After considering the needs of users, we quantitatively evaluated an embodied locomotion interface called the NaviChair according to usability needs and fulfillment of system requirements. Specifically, we investigated influences of locomotion interfaces (joystick vs. an embodied motion cueing chair) and display type (HMD vs. projection screen) on a spatial updating pointing task. Our findings indicate that our embodied VR locomotion interface provided users with an immersive experience of a space without requiring a significant investment of set up time.

Keywords: Spatial orientation, locomotion interfaces, immersion, usability.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems-Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces-Input devices and strategies

1 INTRODUCTION

Over the last few years, we have witnessed the rapid growth of Virtual Reality (VR) technology into both consumer and industry domains. Although this has been led mainly by the creation of affordable, high quality consumer displays, the need to develop more capable and user friendly locomotion interfaces is seen by many as the next great task along the road to VR. Several important issues stand out when considering the need for VR locomotion interfaces. One of the longstanding challenges in VR has been related to deficits seen in spatial orientation and navigation performance [1]. When users become lost or disoriented in VR, frustration can ensue and what would be an otherwise positive experience can be rendered a discouraging ordeal. Additionally, we found several other important factors for a successful locomotion interface: **Ease of Setup, Low Profile, Learnability, Ease of Use, Low Fatigue, Affordable, Sensory Immersion, Social Interaction,** and **Safety**.

We investigated low-cost embodied locomotion prototypes, including the “Joyman” by Marchal et. al. [2] and the “ChairIO” design of Beckhaus et. al. [3]. The Joyman relies on the use of hands, which restricts the use of any hand-based controls. The ChairIO, however, uses leaning on a flexible stool to control simulated self-motions and thus does not require the use of hands to control locomotion, and general user tests were positive in terms of controllability; most users were able to learn to use the chair quickly and easily. We found that the embodied seated locomotion interface based on previous work by Beckhaus et al. [3] and recently investigated in a generic experimental environment setting by Kitson et al. [4] best fulfilled our needs.

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The NaviChair prototype (see **Figure 1**) consists of augmenting a commercially available Swopper chair with a low-cost tracking system, allowing the user to move through a virtual environment (VE) by leaning and rotating their body to control their position and orientation within an immersive display. While the original ChairIO interface required a prohibitively expensive electromagnetic motion tracking system, the NaviChair instead uses an accurate and inexpensive 6DOF TrackIR 4:PRO visual tracking system. This allows us to track the chair’s deflection (yaw, pitch and roll) about a central pivot point at the chair’s base.

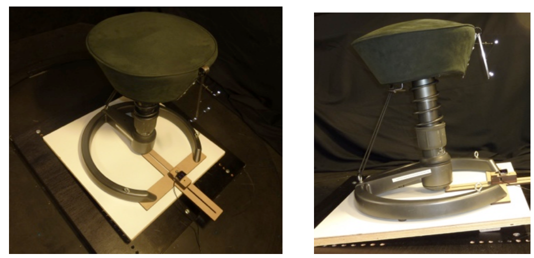

Figure 1: NaviChair prototype

2 METHODS

We assessed 32 students (17 female), aged 19-34 (M = 23.9) for usability and experience of the NaviChair within a VE of a proposed Student Union Building project.

Our evaluation requirements sought to answer these questions:

1) How do the NaviChair and joystick locomotion interfaces compare on measures of spatial orientation, pointing task response time, and ratings of motion sickness, immersion, intuitiveness, and controllability?
2) How do the HMD and 3D projector display compare in terms of user performance on measures of spatial orientation, and ratings of motion sickness and immersion?
3) What feedback do users have on the NaviChair locomotion interface and how might it be improved?

2.1 Stimuli and Apparatus

Two locomotion interfaces were evaluated: our NaviChair interface and a wireless, modified Logitech Freedom 2.4 joystick that allowed yaw, forward/backward, and sideways locomotion. The joystick was chosen for comparison as a “gold standard” locomotion interface that has been optimized for decades and is familiar to users. Thus, we expected participants to do well with the joystick, and if the NaviChair performed as well or better it would indicate promise for future development. We compared two displays: an Oculus Rift DK2 head-mounted display (HMD) and a 2.12 × 1.2m projection screen with a Benq W1080ST 3D projector, and each had a comparable diagonal field of view (FOV) (Oculus Rift 110°; projection screen 90°). Both implemented stereoscopic 3D. For this study we created 2 practice paths and 2 experimental paths through a Student Union Building project. The practice paths included 2 object locations each, while the experiment paths included 5 object locations. Each location was randomly assigned an object: a lamp, a train, a plane, a boot, a car, or a pop can. Each path was assigned to a different floor with a different layout to prevent learning transfer.

2.2 Procedure

After receiving written informed consent, the display adjusted, and stereo blindness tested, the participant was asked to give their current 0-100% rating of motion sickness. After the experimenter first demonstrated the locomotion interface, the participant was instructed to remember their starting location, and then follow a red guiding sphere through the environment until they reached the next target object, as illustrated in youtu.be/WvZGGAHXwI8. This sphere moved at 1.5 m/s, the same as the maximum translation speed, and waited if the user lagged more than 2.5 m behind. At each target location, participants were instructed to use the joystick to point towards all previously visited objects including the starting location. Following the demonstration, the participant completed the practice path independently, and continued to the main task if no motion sickness was present. After completion, they rated their motion sickness again and drew a map of this new-guided path. This procedure was repeated for the second interface. After the main task was complete, the participant was given a short comparison trial of the other display (i.e., if in the HMD condition, they used the 3D projector and vice versa) using the NaviChair interface and rated their motion sickness a final time. Finally, they completed a post-experiment interview that related to gaming experience and immersion, controllability and ease-of-use of the interfaces.

3 Results and Discussion

We analyzed mean absolute pointing errors to investigate potential effects or interactions of the factors locomotion interface (within), display (between), gender (between), and pointing location (within) using a mixed-design 2x2x2x5 ANOVA. As illustrated in Figure 2 (top), absolute pointing errors increased over the 5 locations of the traveled path $F(4, 140) = 3.523$, $p = .009$, $\eta^2 = .091$. This suggests that the task got successively harder and participants got increasingly disoriented the more pointing objects they had to update along their path. While there was no significant main effect of interface (Joystick vs. NaviChair), there was a significant main effect of display: Pointing errors were overall lower for the Oculus Rift HMD ($M = 34.78$, $SE = 2.58$) than the 3D projection screen ($M = 42.46$, $SE = 2.54$), $F(1, 139) = 4.500$, $p = .036$, $\eta^2 = .031$. This was somewhat surprising as previous research would have predicted improved orientation performance for the NaviChair as it includes motion cueing [8]. There was also a significant interaction between locomotion interface and gender. That is, females had a lower pointing error using the NaviChair ($M = 38.39$, $SE = 3.04$) compared to the joystick ($M = 44.97$, $SE = 3.24$), and males had a higher pointing error using the NaviChair ($M = 37.57$, $SE = 2.83$) compared to the joystick ($M = 33.58$, $SE = 3.01$), $F(1, 139) = 5.280$, $p = .023$, $\eta^2 = .037$ (see Fig. 2). Put differently, whereas women and men performed similarly for the NaviChair, women's performance decreased when switching to the joystick whereas men's performance increased, which might suggest potential gender differences in their familiarity with the joystick. This stands in contrast to Grechkin and Riecke's study [5], but aligns with Kitson et. al. [4]. The joystick resulted in lower mean immersion ratings ($M = 48.13$, $SE = 2.91$) compared to the NaviChair ($M = 64.83$, $SE = 2.28$), $F(1, 30) = 25.854$, $p < .001$, $\eta^2 = .463$. When using the joystick, participants reported higher mean controllability ratings ($M = 83.61$, $SE = 2.76$) compared to the NaviChair ($M = 57.56$, SE = 3.21), $F(1, 30) = 50.610$, $p < .001$, $\eta^2 = .628$. Similarly, the joystick yielded higher intuitiveness ratings ($M = 79.10$, $SE = 13.96$) compared to the NaviChair ($M = 64.88$, $SE = 16.88$), $F(1, 30) = 23.065$, $p < .001$, $\eta^2 = .435$. Using the HMD increased mean motion sickness ratings ($M = 22.45$, $SE = 3.60$) compared to the projection screen ($M = 6.19$, $SE = 3.60$), $F(1, 30) = 10.189$, $p = .003$, $\eta^2 = .254$. The locomotion interface did not significantly affect motion sickness.

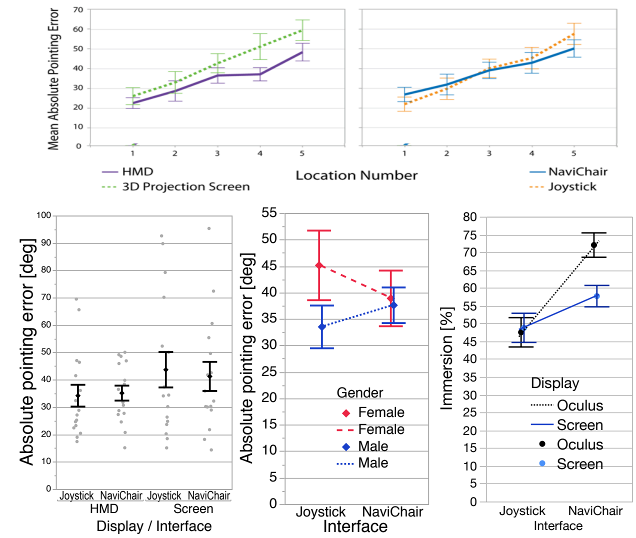

Figure 2: Means and standard errors for the different conditions.

4 Conclusion

Users reported the NaviChair was a fun and attractive locomotion interface, and with more practice it could potentially grant a similar level of controllability as the joystick. The main advantage with the NaviChair appears to lie in the enhanced sense of immersion, specifically when used with the HMD. Still, the appropriateness of the display depends on whether users wish to engage with others (projection screen) or be more immersed (HMD). Interviews yielded ideas for future development and improvement of the chair, which we plan to implement in future design iterations.

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