Evaluating Positional Head-Tracking in Immersive VR for 3D Designers

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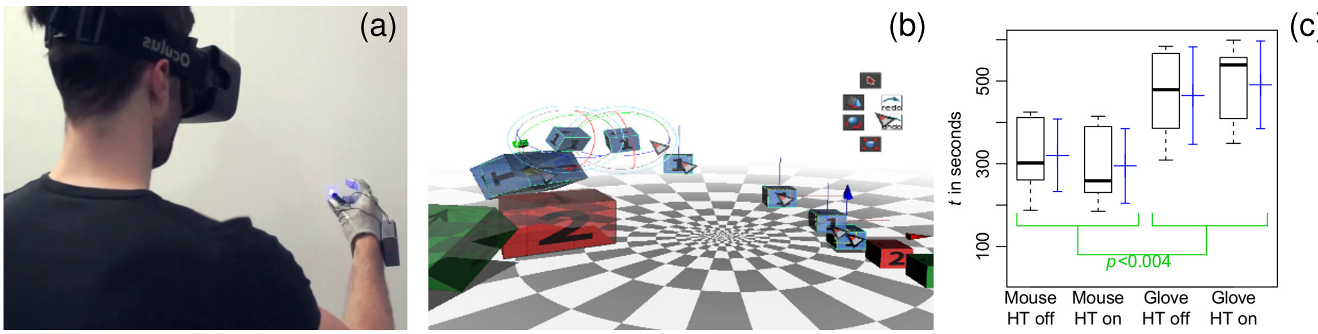

Figure 1: Our study analyzed the effect of positional head-tracking on task performance in a 3D object placement task. (a) The experimental set-up in the glove condition. (b) Illustration of the task: Translating, rotating, and scaling objects on the right to match objects on the left. Stages in the transformation of the blue object are shown in this composite. (c) Task completion time. The blue bars indicate mean and SD.

Abstract

With the ongoing introduction of wide-FOV VR head-worn displays into the consumer market, the application of VR 3D UIs to professional work environments is attracting increasing attention. One of the most conspicuous concepts is immersive 3D modeling and content creation. In spite of the long research history, there have been very few analyses of the effect of 3D UIs on productivity in 3D design. In this work, we explore the effect of positional head-tracking on task performance in 3D design. Previous studies have come to different conclusions on the importance of head-tracking and did not investigate professional 3D modeling tools. In contrast, we performed a user study with design students using professional software on a task that closely emulates their work. Surprisingly, we did not find a significant effect of head-tracking on task-completion time, neither when using a traditional 2D mouse nor when using a pinch glove as a 3D input device.

Keywords: Virtual Reality, Immersive Authoring

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, Augmented, and Virtual Realities

1 Introduction

Many prototype 3D UIs for 3D design have been suggested over time, but there have been relatively few studies that analyze workflows typical of 3D design and evaluate 3D UI concepts that fit these characteristics. In our previous research, we analyzed the work situation of 3D media professionals and found that 3D UIs or 3D input devices have so far failed to appeal to designers for adoption in their daily work [5]. This may be related to a lack of understanding of how specific UI design factors relate to work requirements.

In a preliminary pilot study to explore how artists use their current 2D mouse-and-keyboard UIs, we noticed a particular recurring behavior of "wiggling the viewpoint," wherein the artist rapidly and repeatedly changes the position of the virtual camera by small amounts, apparently in an attempt to gain a better understanding of the 3D shape of the virtual scene in the editor by emulating head-motion parallax. From this, we theorized that an immersive 3D UI could offer increased efficiency, at least in part because positional head-tracking (PHT, also called head-coupling) would provide the necessary parallax effect automatically. To make our results relevant to 3D design, we conducted a user study with 3D artists on a 3D object selection and transformation (translation, rotation, and scaling) task and UI based on 3D design work (Figure 1). Our within-subject study examined performance while wearing a stereoscopic head-worn display (HWD), comparing a 2D mouse with a 3D pinch-glove, and the presence or absence of PHT.

Our results provide no evidence for a statistically significant effect of PHT on task performance, neither when using the 2D mouse nor when using the 3D glove. These results question the common belief in the importance of parallax depth cues from PHT.

2 Related Work

Several publications have analyzed the effects of PHT on task performance in VR and AR 3D UIs, but came to contradictory conclusions. Some have found it beneficial [2, 1, 6, 8], some have found no effect [4, 7] and some have even found a negative effect [2, 3].

Some of these analyzed the effect of stereo vision and PHT on task performance in fish-tank VR for non-interactive observational tasks. Arthur et al. [2] found that PHT alone (without-stereo) was slower than with stereo and even slower than static monoscopic and stereoscopic images, but that it decreased the error rate. In the stereo viewing condition however, they found that PHT improved both time and error rate. Ware and Franck [8] found that parallax motion from PHT improves performance by a factor of 2.2.

Other fish-tank VR user studies had participants perform basic translational pointing or positioning tasks. Boritz and Booth [4] found that head-tracking improved performance in the monoscopic display condition, but degraded performance in the binocular stereo condition. However, this effect was only present during the first trials and quickly wore off as participants adjusted to the task. Teather et al. [7] could not find evidence for any effect from PHT.

In some studies, the VR environment was immersive to some limited extent, and the cursor and 3D input device were aligned.

Arsenault and Ware [1] performed a study in which participants showed significant improvements when head-tracking is enabled. However, the experimental design forced them to change their viewing angle by about 18°, causing a misalignment of the hand and virtual cursor when head-tracking is disabled, which may have caused the effect. Bajer et al. [3] showed that head-tracking actually made participants slower in some conditions. Sandor et al. [6] found that one of the two conditions which did not include PHT significantly decreases performance. However, the conditions differed in several factors and head-tracking is only mentioned as one of three possible explanations for the observed effect.

3 USER STUDY

We performed a pilot study with one professional artist and one amateur, in which we examined their habitual 2D UI workflow. We instructed them to continue working on their own projects as they normally do, while we recorded their actions with a video camera pointed at their computer. Analyzing their 2D workflow, we found that they performed frequent and rapid changes of viewpoint (camera position) on a very small scale—too small to see a different part of the object—which ended very close to the original position. These actions make up about 41.6% of all viewpoint changes and about 7.7% of total work time on average. The intended purpose of this behavior seems to be to gain a better spatial understanding of the virtual 3D object on the monoscopic monitor via a slight "wiggle" of the virtual camera, which produces a parallax motion. This is in accordance with our previous findings [5], in which 3D artists reported that they used camera controls extensively or even constantly. We theorized that in a VR work environment, PHT might make this operation unnecessary, improving work performance.

To test this hypothesis, we developed a prototype 3D modeling UI based on Autodesk Maya. This UI plug-in makes it possible to use Maya with an Oculus Rift DK2. The input device was either a normal 2D mouse or a 3D pinch glove. When the mouse was used, a 2D cursor was displayed in the dominant-eye view only. The UI was the same as in Autodesk Maya with two exceptions: a marking-menu on the right mouse button, and viewpoint navigation on the middle mouse button. The 3D input glove was made from a thin cotton glove and conductive threads. It featured up to eight buttons, of which only the most basic four were used in this study: the main interaction button, a button to invoke the tool menu, an undo button, and a navigation button to change the virtual viewpoint ("grabbing-the-air navigation" metaphor). When using the glove, a 3D arrow was rendered at the location of the participant's thumb. The UI was the same for both mouse and glove conditions, except for the addition of a "6DOF Tool" for the glove, which allowed simultaneous control of translation and rotation. The control/display ratio was 1:1 in the glove condition, and 1cm:14.7° FOV in the mouse condition. PHT can be turned off and on by the experimenter at any time. When off, it produces the effect of looking at a virtual 3D monitor large enough to fill the complete FOV when looking straight ahead. Since PHT is disabled, it appears to follow translational head motions. Independent of PHT, rotational head-tracking is always enabled.

We recruited nine participants from Kyoto Saga University of Arts: seven students, one university staff member, and one professional 3D artist (five female, ages 19–35, mean age 22.2, seven right-hand dominant). All had at least one year prior experience with 3D design software. Prior to the trials, they tested the glove-based 3D UI for 30 minutes, following a tutorial to get used to immersive modeling and the glove. After this session, a rest period was given. Then, participants were timed on a 3D object selection-and-transformation task with primitive 3D objects. Two groups of 3D boxes were displayed, one set being the "goal" arrangement, the other being the "source" objects to place. The task was to transform each "source" object in the same way and to the same place as its corresponding "goal" object. This task involved nine degrees of freedom (DOF): three DOF each for translation, rotation, and scaling. The "goal" arrangement was chosen randomly from a set of ten prepared scenes. During half the trials, PHT was switched on or off by the experimenter, without informing the participants. However, rotational head-tracking was always enabled. The first set (three object transformations) in every block was treated as a training set and removed from the sample. Some measurements were lost, due to technical problems or difficulties in the time schedule not allowing all conditions to be tested. The final analysis contains 30 three-object sets in the mouse conditions (performed by eight of the nine participants), and 14 three-object sets in the glove conditions (performed by five of the nine participants), totaling 132 object-transformation performances.

Figure 1(c) shows a summary of the recorded measurements. When using the mouse, mean task-completion time was 314s without PHT (SD=111s), and 290s with PHT (SD=97s). When using the 3D input glove, mean task-completion time was 431.4s without PHT (SD=125.6s), and 459s with PHT (SD=127.2s). Analysis of within-subject performance showed a significant difference between using the 2D mouse and the 3D input glove (average improvement of 159.4s; $p < 0.0035$), but no significant effect from PHT, neither for the 2D mouse nor for the 3D input glove. (Mouse: difference of means $\approx 25.4s$ (7.7%), $p > 0.1$; Glove: difference of means $\approx -25.8s$ (-6.4%), $p > 0.49$). We considered extending the user study to find more minute differences in task performance, but a power analysis using our sample to estimate population variance (i.e., assuming that future participants would exhibit a similar variability as previous ones) indicated that this was impractical, as we found that we would need $n > 77$ and $n > 76$ respectively for a test of power 0.95. This indicates that the expected effect of PHT is small compared to other factors. Our results show an effect size r of 0.1 (Cohen's $d \approx 0.2$), which is considered small. Conversely, they express 95% confidence that the performance improvement for PHT is $< 17\%$. We further analyzed the recorded motion data and found that participants moved their head significantly less when using the mouse (Motion volume: $\approx 0.0066m^2$ (mouse) vs $\approx 0.0257m^2$ (glove); $p < 0.008$).

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