Extended Sliding in Virtual Reality

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ABSTRACT

Although precise 3D positioning is not always necessary in virtual environments, it is still an important task for current and future applications of Virtual Reality (VR), including 3D modelling, engineering, and scientific applications. We focus on 3D positioning techniques in immersive environments that use a 6DOF controller as input device and present a new technique that improves 3D positioning performance in VR, in both speed and accuracy. Towards this goal, we adapted an extended sliding technique to VR systems with a controller as input device and compared it with previously presented 3DOF positioning techniques. The results showed that our new Extended VR Sliding technique significantly improved the accuracy for 3D positioning tasks, especially for targets in contact with the scene.

CCS CONCEPTS

• Human-centered computing • Human computer interaction (HCI) • Interaction techniques

KEYWORDS

3D positioning, object sliding

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1 Introduction

3D positioning refers to the task of changing the 3D position of an object, where 3 degrees of freedom (DOFs) have to be controlled. In this work our goal is to create better user interfaces for 3D object positioning in VR, and we concentrate on speed, precision, and usability. Speed and precision are very important for applications such as creating 3D models for industrial design or architectural mockups. Our goal is to have both experts and novice users benefit from easy to use, efficient, and accurate 3D positioning techniques. Our work also provides guidelines for 3D user interfaces for VR systems.

While the mouse can be used for 3D positioning tasks in VR [Sun et al., 2018], it is not the most natural input device for an HMD-based VR system, which permits the user to move around. The mouse is only usable when there is a stable surface, e.g., when users are seated at a desk or at least in front of a standing desk. When the user is wearing an HMD and is standing (or sitting on a swivel chair), the user needs to rely on mid-air manipulation, where 6DOF input devices provide more natural input mappings.

The contributions presented here are: (1) New mappings for mid-air 3D positioning with controllers in VR that improve accuracy and (2) Guidelines for creating efficient and precise 3D applications that use 6DOF controllers: use constraints if possible, avoid 3D widgets for distant objects manipulation, use non-dominant hand for confirmation, avoid controller-object offset, and support 3DOF free-hand fine adjustment.

2 Related Work

Finding appropriate mappings from 3D hand to object movements that achieve satisfactory precision is challenging [Mendes et al., 2019], especially for objects beyond arm's reach in VR. Some interaction metaphors apply only within reach of the user, e.g., the virtual hand technique [Mine, 1995], where users intersect the virtual representation of their hand with the object to select and then directly manipulate it with a one-to-one mapping. For manipulating distant objects, the Go-Go technique [Poupyrev et al., 1996] extends the reach of the virtual hand non-linearly. HOMER uses ray-casting for object grabbing followed by hand-centered manipulation [Bowman and Hodges, 1997]. The authors of this work also introduced Ray-Casting-with-Reeling, which changes the length of the ray and allows the user to change the distance where the object is placed. Poupyrev et al. compared Go-Go and ray-casting and found that both techniques have their strengths and weaknesses [Poupyrev et al., 1998]. They identified that ray-casting (without reeling) performs better only in positioning tasks that do not require a (substantial) change of object distance from the viewer.

Some techniques scale down the control/display (C/D) ratio from hand to object movement to increase precision, e.g., PRISM [Frees et al., 2007], which varies the C/D ratio based on hand speed, or scaled HOMER [Wilkes and Bowman, 2008]. A reduced

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ratio introduces an offset between hand and object positions, which can lead to jumps of the hand representation. For distant object manipulation, Go-Go+PRISM [Auteri et al., 2013] adjusted the C/D ratio from PRISM to Go-Go, which improved precision.

DOF separation is another common solution to improve mid-air manipulation. Separating DOFs can lead to better manipulation performance than controlling all DOFs simultaneously [Masliah and Milgram, 2000]. Some work [Caputo et al., 2018] [Mendes et al., 2017] introduced axis-based widgets to make it easier to control objects accurately within arm's reach. However, these techniques are not suitable for distant objects and require multiple selections and switches between different interaction modes.

3D selection and positioning techniques suffer from the Heisenberg effect [Bowman et al., 2001], where the slight wrist movement caused by a button press can affect the precision of object selection or placement. PRISM [Frees et al., 2007] mostly eliminated the Heisenberg effect. Another solution is bimanual interaction, e.g., [Batmaz and Stuerzlinger, 2019] [Kopper et al., 2008]. Some techniques used both hands for manipulation, e.g., Handle Bar [Song et al., 2012] or Spindle+Wheel [Cho and Wartell, 2015]. Yet, asymmetric bimanual gestures can increase the cognitive burden for users. Also, the prolonged use of both hands in mid-air can be fatiguing, due to the "gorilla arm" effect, a universal drawback of mid-air interaction [Jang et al., 2017].

Many 3D positioning techniques used constraints to assist with object manipulation and constrain the position of the manipulated object to other scene objects. Currently, constraints are not widely used for 3D manipulation in VR. Building on Object Associations [Bukowski and Séquin, 1995] and observations of real-world interaction, Oh et al. [Oh and Stuerzlinger, 2005] presented object sliding, where the object follows the 2D cursor directly and slides on any surface behind it, i.e., the moving object always stays attached to other objects. An extended version generalized sliding to floating or colliding objects, giving users direct control of the third DOF [Sun et al., 2016]. Sun et al. compared traditional sliding with the mouse and Vive controller [Sun et al., 2018] and here we adapt their work to VR systems. Yet, we believe that with extended sliding the mouse would still perform better than the controller. Thus, our objective in this work is to identify an appropriate mapping for extended sliding with a VR controller.

3 Extended VR Sliding

With Shift-Sliding [Sun et al., 2016], pressing the Shift key changes to a mode, where the object moves orthogonal to the sliding plane, which forces the object to float. For traditional sliding in VR with the Vive controller, we adapted a previous method [Sun et al., 2018]. The user performs selection via ray-casting by pressing the trigger button on the controller. Then, the user can slide the object on the scene surfaces through pointing the controller at different locations.

To adapt Shift-Sliding, we designed and implemented an *Extended VR Sliding* method where the Shift key from the desktop method is mapped to pressing down on the Vive controller trackpad. Figure 1 illustrates Extended VR Sliding. A virtual sphere cursor follows the direction of the controller ray and snaps onto the geometry that the ray intersects first. In Figure 1 left, the user pressed the trigger button to select the object under the controller ray and started sliding the object by moving the controller. When they also pressed the trackpad during sliding, further controller movement then lifts the object orthogonal to the current contact surface, see Figure 1 middle. In Figure 1 right, if the users released the trackpad while still holding the trigger, further controller movement moves the object parallel to the original sliding surface. When the object is lifted from a surface, we render it in a cyan color. Lifting is implemented as a 2DOF operation, as up-down movements relative to the surface that the object was lifted from as well as some form of "sideways" movements are possible.

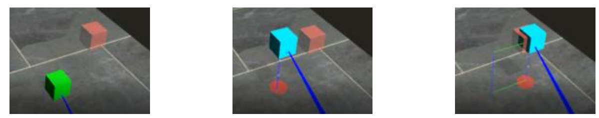

Figure 1: Extended VR Sliding. The manipulated object is lifted from the floor, while still being on the ray. The semi-transparent target position is floating above the floor.

With Extended VR Sliding, we do not scale the C/D ratio from hand movement to object movement. To reduce the "Heisenberg" effect, the user uses the trigger on the other controller in their non-dominant hand to release the object.

With ray-casting in VR, the user selects the object with the controller ray. In the normal ray-casting condition, the length of the ray is fixed after selection and the object stays at the end of the ray, which enables the user to manipulate all three DOFs for positioning but restricts the amount of change in visual depth. When a significant change of depth is needed, we support Ray-Casting-with-Reeling [Bowman and Hodges, 1997], by allowing the user to adapt the ray length through pressing the top/bottom of the controller trackpad.

To evaluate our new technique, we also implemented two virtual hand techniques that adjust the C/D ratio between the user's and the virtual hand: Go-Go and Go-Go+PRISM. With both techniques, we used a 3D model of the controller as representation of user's hand. In a pilot study, we compared Extended VR Sliding, Ray-Casting-with-Reeling, Go-Go, and Go-Go+PRISM. The results showed that Go-Go was significantly faster than Extended VR Sliding and Ray-Casting-with-Reeling. Technique did not have a significant effect on error measure. Four participants found Go-Go+PRISM too slow and physically uncomfortable to use. Five participants found the mappings used by Extended VR Sliding unintuitive or found the mode change to be challenging. Three participants commented that they did not like Ray-Casting-with-Reeling since they had to press the trackpad on the Vive controller while holding the trigger button.

4 Simplified Extended VR Sliding

Based on the results of the pilot study and especially the user feedback, we decided to modify the Extended VR Sliding technique to improve its usability. In Extended VR Sliding, users had to press on the trackpad to lift the object off the surface. Technically, this lifting action afforded only 2DOF, yet some users perceived it to be more like free-hand manipulation. When the user released the trackpad, the system then transitioned to a mode that affords 2DOF sliding parallel to the surface that the object was previously in contact with, as determined by the controller ray. Some users did not understand this transition well and found it hard to position an object with precision in this phase, and therefore did not perform well with floating targets.

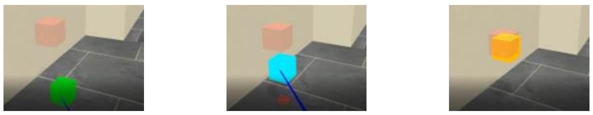

Figure 2: Right image: the modified free-hand adjustment phase. Here, the user moves the object with controller movement through a scaled virtual hand mapping.

Although more training could help users to understand Extended VR Sliding better, we decided to adapt the technique for ease of understanding, by simplifying the final sliding phase. Instead, we now make the controller ray disappear after the user releases the trackpad. The users can then move the object with their (virtual) hand movement in 3DOF with a magnification mapping (C/D scaled by 5). To highlight the mode change, we rendered the object in yellow color during this phase. See Figure 2. Overall, the sliding and lifting phases are used to move the object close to the target position, and the fine adjustment phase uses free 3D hand movements. We hypothesized that this change would make the technique more natural and easier to use.

5 User Study

We designed a user study to evaluate the performance of the simplified Extended VR Sliding technique. Based on the outcomes of the pilot, we compared only with Go-Go. This study focused on 3D positioning of distant objects, i.e., when the initial position of the object is far away from the user. The participants sat in front of a table, wearing the Vive headset. We made the virtual room ten meters deep. See Figure 3. In all trials, the object was a cube with 30 cm side length. The starting and target positions were at least two meters away from the user.

We asked participants to move an object from a starting to a target position as quickly and as accurately as possible in several scenes. The target position was semi-transparent. We gave participants 3 minutes of training before each condition, which introduced them to the techniques in a playground different from the experimental tasks. When the participants pressed the non-dominant trigger to confirm the final position the software advanced to the next trial. There were two dependent variables: positioning time (in seconds) and error distance (in centimeters). Timing started when the object was first selected and ended when the user pressed the non-dominant trigger. The error distance was the 3D distance between the object's and the ideal target position's centers. From this we derived a relative error measure by computing the ratio of the error distance over the object size (30 cm). The study took about 30 minutes per participant. Finally, after they finished all tasks, we asked users to complete a questionnaire, where they rated the ease of use, perceived speed, and fatigue of each technique using a 7-point Likert scale. We also asked participants about their preferred technique and freeform feedback on the experiment.

Figure 3: Illustration of a task scene. The target position (near, on the right) is rendered semi-transparently and floats above the floor. The depth distance change is large.

The experiment had a 2 (technique) x 2 (depth distance change) x 2 (object contact) within-subject design, and we counterbalanced the order of the tasks using Latin square to reduce learning effects. Each sub-condition had 5 repetitions and thus each participant performed 40 trials in total. We compared two **techniques**: our simplified Extended VR Sliding technique and Go-Go. We included two levels of **depth distance change**: small and large. In the Small condition, the depth distance change was less than 1 m and in Large more than 5 m. Except for moving the controller with their arm, users were still able to complete all trials without significant body movement. The third independent variable, **object contact**, had two levels: contact and floating. For contact, all target positions were in contact with the rest of the scene. For floating, all targets were at least 1 m from the closest scene surface.

We measured positioning time and positioning accuracy. We hypothesized that Extended VR Sliding would be more accurate than Go-Go (**H1**). Also, due to the modifications we introduced, we hypothesized that Extended VR Sliding would be as fast as Go-Go (**H2**). Finally, we hypothesized that Extended VR Sliding would be significantly faster and more accurate for targets that are in contact with the scene, while object contact would not have a significant effect on Go-Go (**H3**).

We used a first-generation HTC Vive (headset, base stations, controllers) and a 3.6 GHz i7 desktop computer, 16 GB, GTX 980 graphics, Unity 2018, and used a desktop monitor to watch the users' actions during the experiments. We recruited 12 students from the local university population (5 female). We did not screen participants for 3D/VR experience. We had ethics approval for the study and participants signed consent forms.

5.1 User Study Results

The data of positioning time and error measure were not normally distributed ($p < .0001$). However, for positioning time and error measure, the skewness and kurtosis of the data were within ±2, and thus we conducted ANOVA tests [George, 2011].

5.1.1 ANOVA Results on Positioning Time. We performed a 3-way (2 Technique x 2 Object Contact x 2 Depth Distance Change) repeated measures ANOVA on positioning time. The results showed that the main effect of Technique on positioning time was significant, $F(1, 11) = 19.32$, $p = .0011$. Go-Go (M =

4.41s, SD = 2.37s) was significantly faster than Extended VR Sliding (M = 5.20s, SD = 2.76s). This did not support our hypothesis **H2**. The main effect of Object Contact on time was significant, $F(1, 11) = 24.13$, $p = .0005$. The Contact condition (M = 4.21s, SD = 2.29s) was significantly faster than Floating (M = 5.39s, SD = 2.74s). The main effect of Depth Distance Change on time was not significant, $F(1, 11) = 3.68$, $p = .0795$.

The Technique x Object Contact interaction had a significant effect on positioning time, $F(1, 11) = 145.89$, $p < .0001$. <Extended VR Sliding, Contact> (M = 3.77s) was the fastest combination. This supports our hypothesis **H3**. However, <Extended VR Sliding, Floating> (M = 6.76s) was the slowest combination. The Technique x Depth Distance Change interaction did not have a significant effect on positioning time, $F(1, 11) = 0.62$, $p = .45$. Still, <Go-Go, Small> (M = 4.20s) was the fastest combination.

5.1.2 ANOVA Results on Error Measure. The ANOVA results showed that the main effect of Technique on error measure was significant, $F(1, 11) = 10.60$, $p = .0079$. Extended VR Sliding (M = 0.255, SD = 0.321) was significantly more accurate than Go-Go (M = 0.344, SD = 0.357). This supports our hypothesis **H1**. The main effect of Object Contact on error measure was not significant, $F(1, 11) = 4.32$, $p = .0614$, nor the main effect of Depth Distance Change on the error measure, $F(1, 11) = 3.60$, $p = .0914$.

The Technique x Object Contact interaction did not have a significant effect on error measure, $F(1, 11) = 0.95$, $p = .3492$. Tukey post-hoc analysis showed that <Extended VR Sliding, Contact> (M = 0.201) was significantly more accurate than <Go-Go, Contact> (M = 0.305) and <Go-Go, Floating> (M = 0.381). This further supports our hypothesis **H3**.

The Technique x Depth Distance Change interaction did not have a significant effect on error measure, $F(1, 11) = 1.00$, $p = .3403$. Tukey post-hoc analysis showed that <Go-Go, Large> (M = 0.373) was the least accurate combination.

5.1.3 Questionnaire Responses. Ten out of 12 participants found Extended VR Sliding neutral or easy to use. Eleven found Go-Go neutral or easy to use. Eight participants found the perceived speed of Extended VR Sliding neutral or fast. Eleven found the perceived speed of Go-Go neutral or fast. Eleven participants found the fatigue level of Extended VR Sliding neutral or low. Nine found the fatigue level of Go-Go neutral or low. Moreover, seven participants rated Extended VR Sliding over Go-Go. One was neutral.

Three participants rated the fatigue level of Go-Go above neutral, as in some situations when the depth distance change was large, the technique required users to stretch their arm fully to reach an object. Five expressed a preference for Simplified Extended VR Sliding. This simplification helped participants to be more precise in the fine adjustment phase and they found the mode change to be easy and natural. When the object had already been slid relatively close to the target, at least three participants used the trackpad merely for mode change, i.e., they forsook the lifting phase and went directly to free-hand mode.

5.1.4 Additional Results. We recorded all actions of the users. Based on these logs, we analyzed users' behaviors in more depth. The average positioning time for <Extended VR Sliding, Contact> was 3.77s, while it was 6.76s for <Extended VR Sliding, Floating>. The difference between these two combinations is due to the two extra phases required to position floating objects. The sliding phase in the floating conditions took 3.12s on average, which was faster than in the contact condition. The lifting phase took 1.47s on average. After releasing the trackpad, the users spent on average 2.17s on fine adjustments.

6 Discussion

Based on the pilot results and user feedback, we simplified our Extended VR Sliding technique with free-hand fine adjustment. Comparing results of the pilot and the main study, we can confirm that the simplified mode change was easy to use and worked better. In terms of error measures, the simplification also improved the accuracy for floating targets.

Although <Extended VR Sliding, Floating> was slower than Go-Go in the main user study, we believe that users could get faster with training. For targets in contact, Simplified Extended VR Sliding performed best for time and accuracy, better than any Go-Go combination. Typically, Extended VR Sliding requires a surface in the scene to slide the object on. If there is no object in the scene, users can still slide the object parallel to their view plane and "lift" the object in the view direction.

Poupyrev et al. found that for object positioning without a substantial depth distance change, ray-casting (without reeling) was significantly faster than Go-Go [Poupyrev et al., 1998]. Still, the performance of Extended VR Sliding was robust to depth distance changes. The Small and Large condition did not have any significant effect on either Extended VR Sliding's positioning time or error measure. Yet, if a scene contains an object that is too far away, users cannot reach it with Go-Go even with full arm extension. We acknowledge that we could have used Stretch Go-Go [Bowman and Hodges, 1997], but that might have been fatiguing and affect speed/accuracy.

Using the trigger button on the user's non-dominant hand for confirmation effectively reduced the Heisenberg effect [Bowman et al., 2001]. This matched the results of previous work [Batmaz and Stuerzlinger, 2019]. Participants quickly adapted to using the non-dominant hand for confirmation without issues.

Teather et al. proposed guidelines for 3D positioning in desktop environments [Teather and Stuerzlinger, 2007], including the avoidance 3D handles/widgets for 3D positioning. We believe this guideline still holds for VR and thus we recommend our Simplified Extended VR Sliding technique.

7 Conclusion

We designed and implemented an Extended VR Sliding technique for 3D positioning. Our user study showed that Simplified Extended VR Sliding significantly improved the accuracy for 3D positioning tasks. For targets that were in contact with the scene, our new technique was significantly faster and more accurate. In the future, we plan to further improve the mappings of Simplified Extended VR Sliding. We also intend to include implementations of our new technique in VR-based 3D modelling software.

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