PRECIOUS! Out-of-Reach Selection using Iterative Refinement in VR

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Figure 1: PRECIOUS technique for out-of-reach object selection: A) selection cone intersecting several objects, B) refinement phase, moving user closer to intersected objects, C) single object selection, D) returning to original position with object selected.

Abstract

Selecting objects outside user's arm-reach in Virtual Reality still poses significant challenges. Techniques proposed to overcome such limitations often follow arm-extension metaphors or favor the use of selection volumes combined with ray-casting. Nonetheless, these approaches work for room sized and sparse environments, and they do not scale to larger scenarios with many objects. We introduce PRECIOUS, a novel mid-air technique for selecting out-of-reach objects. It employs an iterative progressive refinement, using cone-casting to select multiple objects and moving users closer to them in each step, allowing accurate selections. A user evaluation showed that PRECIOUS compares favorably against existing approaches, being the most versatile.

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Interaction styles, Graphical User Interfaces

1 Introduction

When interacting in virtual environments, object identification is essential, so that the system can understand which virtual object should users' actions be applied to. In virtual environments that support mid-air hand tracking, object selection is usually performed by intersecting the object with the hand or a representative virtual cursor. As expected, this approach is not suited for cases where the desired object is placed outside arms-reach. To overcome physical constraints, ray-casting and arm-extension techniques allow users to select out-of-reach objects. Pointing using ray-casting resorts to a mathematical ray to intersect objects. In arm-extension techniques such as Go-Go [11], the reach of users' virtual hand is interactively modified when they go beyond a certain threshold distance. Stretch Go-Go [2] improves on Go-Go, by being able to infinitely extend the virtual arm.

However in some cases, the selection can be imprecise and lead to undesired selections. This can be overcame by using a Progressive Refinement strategy [7]. For instance, Flashlight [8], a variant of ray-casting, uses a cone instead of a ray to select a group of objects, and uses an automatic refinement based on the object proximity to the center line of the cone to choose a single object. Grossman and Balakrishnan [6] improved ray-casting by using forward and backward hand movements to disambiguate between the intersected objects. Zoom-based techniques have also been proposed [1, 3], which employ a Progressive Refinement strategy by diminishing the field-of-view until the desired object appears large enough to be selected. However, these techniques were developed for non-immersive and non-stereoscopic scenarios, and may not be suited for Virtual Reality (VR) as they might led to user discomfort or cybersickness. There are few works that employ Progressive Refinement in VR, but they require additional interactive surfaces to disambiguate selection [10], or completely change the virtual environment [4], which may disrupt immersion.

2 PRECIOUS

We developed a new technique for out-of-reach selection in VR, PRECIOUS: Progressive REfinement using Cone-casting in Immersive virtual environments for OUt-of-reach object Selection, depicted in Figure 1. It offers an infinite reach, and resorts to a flashlight metaphor [8] with a cone as a selection volume, casted from users' hand. The orientation of users' hand defines the direction of the cone. While pointing, users can make the cone aperture wider or smaller, and change the cone's reach. Differently from the Aperture Selection technique [5], we change cone's aperture using users' wrist rotation. When the wrist is rotated clockwise, the aperture of the cone increases until the opening angle reaches 15 degrees. Analogously, if rotated in the opposite direction, the aperture will decrease until a 7 degrees angle is achieved. To manipulate cone's reach we adopted a similar approach to the used on Stretch Go-Go [2] to control users' virtual hand. As such, we define three spherical regions around the user, but we center them in the hip side corresponding to the dominant hand. When users extend their hand into the outermost region (more than 50 cm from the shoulder), the cone will stretch in the pointed direction at a rate of 5 m/s. Placing the hand in the innermost region (less than 30 cm), will make the cone decrease in size with the same speed. While the hand is placed in the middle region (from 30 to 50 cm), the cone's reach remains unchanged. To help users understand in which region their hand current is, we place a widget next to users' hands when the cone is active, which shows the three regions with an arrow pointing towards the one currently active.

The usage of a selection volume instead of a ray can lead to several objects being intersected by it. When this happen, a disambiguation mechanism is triggered. In our approach, we drew inspiration from previous zoom techniques [1], but instead of changing the camera's field-of-view, we move users closer to selected objects. To move users we perform an instantaneous teleport action [9]. This process is iteratively repeated until a single object is

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selected or, if users desire, can be stopped at any time to select a group of objects, supporting also the selection of multiple objects. When the refinement process is over, users are placed back in their starting position. When two objects are very close to each other, it might be difficult to manipulate the selection cone in such a way that it only intersects a single object. To prevent user frustration we made these final stages of the refinement process easier. Following a canvas disambiguation approach [4], we place them side-by-side in front of the user, while hiding the remaining objects in the scene. Although an higher number of objects could be used to trigger this final step, we opted to perform it only when the cone intersects two, so that user immersion is disrupted as little as possible.

3 User Evaluation

To validate PRECIOUS (PRE), we compared it against two techniques from literature: Stretch Go-Go [11] (SGG) and Flashlight [8] (FL). We counted with a total of 18 participants (2 female).

Our prototype was developed in Unity3D and run in a Samsung Gear VR headset with a Samsung Galaxy S6 smartphone. Users' full body was tracked using three Microsoft Kinect V2 depth cameras. We used a custom device that tracks 3 DOF hand orientation with an IMU and features a pressure pad to detect if the hand is opened or closed. An object selection action is started when some pressure is detected. When users close their hand with added pressure, a multiple object selection is triggered.

Participants were requested to complete a set of four tasks for each technique, and all consisted in selecting a cactus in a virtual representation of an urban environment. In these tasks, we varied the distance of the cactus from the user and the amount of objects surrounding it (Task 1: near and alone, Task 2: far and alone, Task 3: near with objects close, Task 4: far with objects close). For tasks where the cactus was near we used distances plausible in room-sized scenarios, whereas in the others we placed it on the other side of a large avenue. Every time participants selected an object other than the cactus, we registered it as an incorrect selection. If users reached 3 minutes in any task, we informed they could stop, and registered it as an unsuccessful attempt.

We found statistical significance in the completion time of all tasks (Task 1: $\chi^2(2)$=17,375, p<.0005; Task 2: F(1.013,8.102)=18.327, p=.003; Task 3: $\chi^2(2)$=19, p<.0005; Task 4: t(9)=-3.802, p=.004). In the first task, FL (avg=10s) was faster than PRE (avg=22s, Z=-2.430, p=.045) and SGG (avg=44s, Z=-3.479, p=.003) and PRE was faster than SGG (Z=-3.574, p<.0005). In this task, all techniques had a 100% success rate. For the second task, FL (avg=6s) was faster than PRE (avg=11s, Z=-2.926, p=.009) and SGG (avg=77s, Z=-2.666, p=.024). PRE had significantly better completion times when compared to SGG (Z=-2.9340, p=0.009). This task revealed the flaws of SGG, as its success rate dropped to 61%, while the other remained with 100%. In the third task, FL (avg=6s) was faster than PRE (avg=13s, Z=-3.030, p=.006) and SGG (avg=28s, Z=-3.296, p=.003). PRE also showed better results than SGG (Z=-2.480, p=0.039). As expected, when the object is moved closer to the user the success rate of SGG increased to 83%, but remaining different from other techniques' 100%. In the final task, SGG had a success rate of only 22%. Others continued with 100%. This task revealed FL (avg=15s) to be faster than PRE (avg=24s). This was the only task where incorrect selections occurred, with FL ($\tilde{x}$=1.5, IQR=3) causing significantly more errors than PRE ($\tilde{x}$=0, IQR=1, Z=-3.21, p=.003). The starting short reach of the cone in PRE required participants to increase it in all tasks, being the major reason why it was slower than FL.

When analysing participants' preferences (Table 1) gathered through a questionnaire with a Likert Scale from to 1 to 5 (5 is better), we identified significant differences in ease of use ($\chi^2(2)$=23.524, p<.0005), fun factor ($\chi^2(2)$=27.180, p<.0005), fatigue ($\chi^2(2)$=18.582, p<.0005) and discomfort ($\chi^2(2)$=22.189, p<.0005) felt. Participants strongly agreed that SGG was the hardest to use (FL: Z=-3,673, p<.0005, PRE: Z=-3,556, p<.0005), less fun (FL: Z=-3,660, p<.0005, PRE: Z=-3.572, p<.0005), most tiring (PRE: Z=-3.441, p=.003) and most discomforting (FL: Z=-3.342, p=.003, PRE: Z=-3.475, p=.003). Statistically significant differences between PRE and FL were not found.

Table 1: Participants' preferences: $\tilde{x}$ (IQR). * indicates statistical significance.

	SGG	FL	PRE
Easiness *	1 (1)	4.5 (1)	4 (1)
Satisfaction *	2 (1)	5 (1)	4 (1)
Physical discomfort *	2.5 (2)	5 (1)	5 (1)
Visual discomfort *	3 (1)	5 (1)	5 (1)

4 Conclusions

In this work we proposed PRECIOUS, a new technique for out-of-reach object selection in VR, which employs a progressive refinement strategy. We evaluated it against Stretch Go-Go and Flashlight. With the results of our evaluation we found that Stretch Go-Go is impractical for objects that are further away than the size of a room. Flashlight provided the fastest completion times, but when the environment is not sparse it is prone to incorrect selections (half of participants committed at least 2 errors in the final task, max=12). Depending in the application context, unwanted selections can have a severe impact on the outcome, by applying actions to a wrong object. PRECIOUS, on the other hand, offers an almost error free selection approach (except for 6 participants that made a single error in the last task) with a small increase in task duration. This makes it a suitable technique to select objects out-of-reach. Moreover, we believe that an increased starting cone's reach in PRECIOUS can significantly reduce its selection times.

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References

[1] F. Bacim, R. Kopper, and D. Bowman. Design and evaluation of 3d selection techniques based on progressive refinement. *International Journal of Human-Computer Studies*, 71(7), 2013.

[2] D. Bowman and L. Hodges. An evaluation of techniques for grabbing and manipulating remote objects in immersive virtual environments. In *Symposium on Interactive 3D Graphics*, 1997.

[3] J. Cashion, C. Wingrave, and J. LaViola. Dense and dynamic 3d selection for game-based virtual environments. *IEEE TVCG*, 18(4), 2012.

[4] H. Debarba, J. Grandi, A. Maciel, L. Nedel, and R. Boulic. Disambiguation canvas: a precise selection technique for virtual environments. In *INTERACT*, 2013.

[5] A. Forsberg, K. Herndon, and R. Zeleznik. Aperture based selection for immersive virtual environments. In *UIST*, 1996.

[6] T. Grossman and R. Balakrishnan. The design and evaluation of selection techniques for 3d volumetric displays. In *UIST*, 2006.

[7] R. Kopper, F. Bacim, and D. Bowman. Rapid and accurate 3d selection by progressive refinement. In *3DUI*, 2011.

[8] J. Liang and M. Green. Jdcad: A highly interactive 3d modeling system. *Computers & Graphics*, 18(4), 1994.

[9] D. Medeiros, E. Cordeiro, D. Mendes, M. Sousa, A. Raposo, A. Ferreira, and J. Jorge. Effects of speed and transitions on target-based travel techniques. In *VRST*, 2016.

[10] D. Medeiros, L. Teixeira, F. Carvalho, I. Santos, and A. Raposo. A tablet-based 3d interaction tool for virtual engineering environments. In *VRCAI*, 2013.

[11] I. Poupyrev, M. Billinghurst, S. Weghorst, and T. Ichikawa. The go-go interaction technique: non-linear mapping for direct manipulation in vr. In *UIST*, 1996.