Investigating the Effect of Distractor Interactivity for Redirected Walking in Virtual Reality

Robbe Cools
KU Leuven, Belgium
robbe.cools@student.kuleuven.be

Adalberto L. Simeone
KU Leuven, Belgium
adalberto.simeone@kuleuven.be

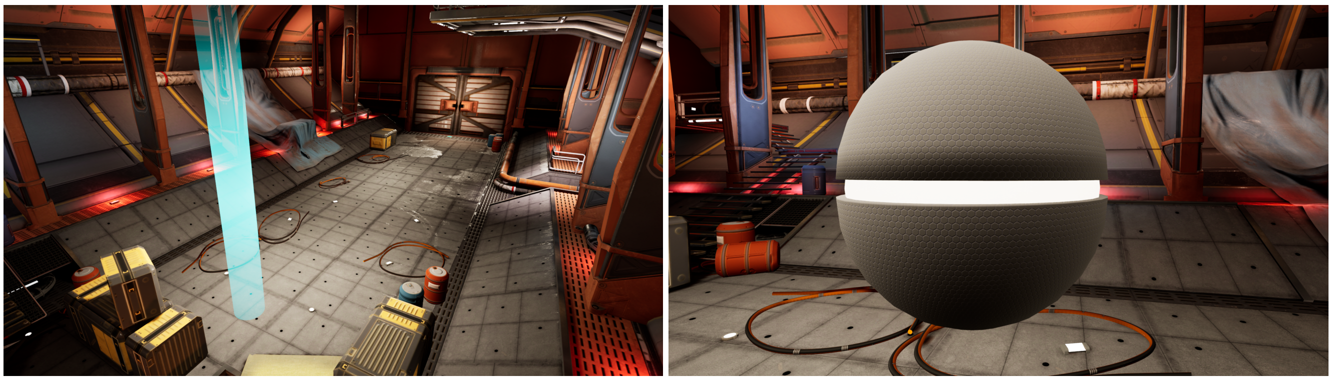

Figure 1: Participants had to reach the area highlighted by the light beam (left) by walking in the Virtual Environment used. Four types of interactive and non-interactive distractors (right) were used to redirect participants in a room-scale area.

ABSTRACT

Due to the mismatch in size between a Virtual Environment and the physical space available, the use of alternative locomotion techniques becomes necessary. In small spaces, Redirected Walking methods provide limited benefits and approaches such as the use of distractors can provide an alternative. Distractors are virtual elements or characters that attempt to catch the attention of the user while the system subtly steers them away from physical boundaries. In this research we explicitly focused on understanding how different levels of interactivity affect user performance and behaviour. We developed three types of continuous redirecting distractors, with varying levels of interaction possibilities, called *Looking*, *Touching*, and *Interacting*. We compared them in a user study to a discrete reorientation technique, called *Stop and Reset*, in a task requiring users to traverse a 30 m path. While discrete reorientation is faster, continuous redirection through distractors was significantly less noticeable. Results suggest that more complex interaction is preferred and able to better captivate user attention for longer.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **Interaction techniques**.

KEYWORDS

Virtual Reality, Redirected Walking, distractors, interactivity

1 INTRODUCTION

Locomotion in Virtual Reality (VR) is one of the main challenges due to the disparity between the Virtual Environment (VE) and the real space available. With the increased popularity of VR applications, several users immerse themselves in relatively small spaces such as their living room. In these scenarios, a 1:1 mapping between the VE and the physical space often becomes impossible. Widely known solutions for small spaces include point-and-teleport [2], controller-based locomotion [6], resetting [18] or redirection techniques [7].

Redirection techniques can be divided in two main categories [14] those that manipulate the gain between the user's real and virtual rotation and translation, and those that manipulate the VE architecture [16]. Continuous gains require large areas, greater than 10 m by 10 m to be employed without users noticing the manipulation. Some form of resetting thus becomes necessary in small spaces [1]. One such method consist in triggering an event to further redirect users when they approach physical boundaries, in the form of a distractor [8]. There have been various implementations [4, 8, 9, 13], some of which have the user interact with the distractor (also called attractor [13]), and some which have no interaction.

In this paper we thus provide an in-depth investigation of how interactivity affects user performance and behaviour. We designed three different distractors based on continuous redirection, with an increasing complexity of interaction. These were compared to a discrete reorientation technique (which allows users to virtually rotate their viewpoint by 180°) in a within-subject study requiring participants to reach a goal area at the end of a 30 m path. Results indicate that, while continuous distractor-based techniques are slower than instantaneous reorientation, they were significantly less noticeable (in terms of self-reported ratings), with the more complex interaction-based distractors being preferred.

2 RELATED WORK

The mismatch between the size of the VE and the physical space available has inspired the design of several techniques. If a large physical area is available, Redirected Walking (RW) represents an ideal solution [7]. However, according to a study by Azmandian *et al.*, spaces of more than 30 m × 30 m are necessary to achieve complete redirection (in "long-walk" scenarios) [1]. When RW is used in spaces of 6 m × 6 m, it is only able to reduce the number of orientation resets by 10%. Domestic settings such as users' living rooms are typically smaller. Alternative solutions become necessary such as leveraging change blindness to manipulate the VE in indoor spaces [15, 16], or changing the appearance of the floor to steer users away from specific areas [12]. Approaches that do not require the manipulation of the VE consist in employing *distractors*: virtual elements or characters which attempt to capture the user's attention in order to steer them away from physical boundaries. In the following we focus on prior examples of this techniques.

Peck *et al.* first proposed the use of distractors and compared this approach to other control techniques [8, 11]. They found that participants were less aware of VE rotation when reorienting using distractors and that contextually appropriate distractors (such as a hummingbird) were preferred. An evaluation of navigational ability comparing Redirected Free Exploration with Distractors to Walking-in-Place and joystick locomotion interfaces *Redirected Free Exploration with Distractors* (RFED) [10] predicts the user's future direction at every frame and rotates the VE so that the future direction is rotated towards the center of the tracked space. The distractor used is a hummingbird, as in previous work [8]. A user study compared RFED with controller-based and walking-in-place (WIP) interfaces. The study found that RFED participants were significantly better at navigating than participants using WIP or controllers.

Chen and Fuchs [3] used a dragon that appears when redirection is needed. The redirection algorithm is a modified version of the algorithm used by Peck *et al.* [9]. To determine when the distractor should appear a "safe circle" is defined with a radius of circa 1 m. The distractor is triggered when the user is outside the circle and the direction to the goal does not intersect the circle. When the dragon appears, it starts breathing fire towards the user, who can shoot at it to make it stop. In the user studies, at least 70% of participants reported being redirected imperceptibly.

In VMotion [13], embedded context-sensitive distractors (referred to as attractors) are combined with visibility control techniques. These require users to perform tasks, such as looking at a bird through binoculars, which limits the field of view. The bird flies in a pre-determined path through the sky and disappears when the VE is rotated 90°. Others require users to interact with an object, such as a piece of amber. By holding it to the sky and rotating until they see the object inside, the system leverages the user focusing on the sky to rotate the rest of the environment.

3 DISTRACTORS

We designed four types of distractors, of which three use continuous reorientation, and one based on discrete reorientation [14]. The continuous reorientation distractors are named after their increasing complexity of interaction: *Looking*, *Touching* and *Interacting*. The discrete reorientation distractor is called *Stop and Reset* because users have to stop and trigger a reset of their orientation. These

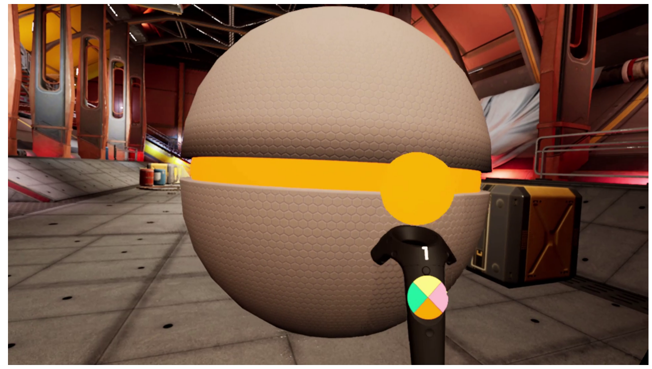

Figure 2: In the *Interacting* distractor, the orb shows the color that the user needs to select on their controller.

techniuqes are all implemented by slight alterations of the appearance or functionality of the distractor used in the subsequent study, a futuristic orb (see Figure 1).

3.1 Looking

Looking is designed as a functional distractor with as little interaction as possible. The minimum that is required is that users follow the distractor with their head movement. In order to operate, the *Looking* distractor requires users to keep looking at it while it rotates around them in a 180° arc. Since the headset we used (a HTC Vive) does not have an embedded eye-tracker, the system assumes that users are looking at the distractor if their forward vector points toward the distractor with a tolerance of 90°. While looking, the system applies a positive or negative gain to the camera rotation (i.e. it accelerates or slows it) to perform the redirection. If the user stops looking at the distractor, the environment stops reorienting itself and the distractor stops moving.

3.2 Touching

The **Touching** distractor requires users to collide their controllers with the sphere. When the center ring of the distractor lights up, users can touch the distractor. Successively, users must wait for the ring to turn white again. The aim of this mechanic was to keep users focused on the interaction, while the environment is rotated around them. If the users do not engage with the mechanic, the gain factor used in the redirection is set to zero.

3.3 Interacting

The **Interacting** (see Figure 2) distractor requires users to engage in a color game. The distractor's ring will light up with a specific color (among four possible choices). Users must touch it by first selecting the same color with the trackpad on their controllers. The currently selected color is displayed through an orb next to the controller. If the color is correct, the distractor will repeat the process with another color. Similar to the other distractors, no redirection occurs if the user stop engaging with it.

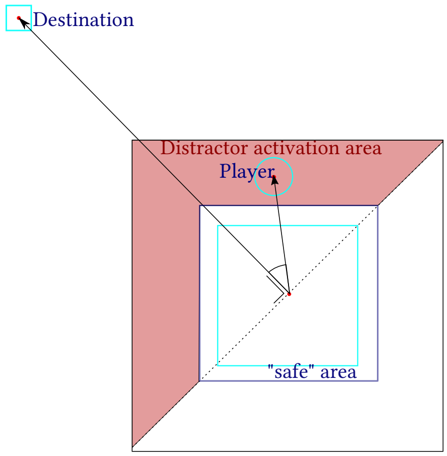

Figure 3: In red, the area where the distractor activates.

3.4 Stop and Reset

The **Stop and Reset** distractor is different from the previous three, as it is based on discrete reorientation. When users move close to the boundary, the distractor will appear in front of them and light up to show that they need to touch it. Touching the distractor triggers a discrete reorientation that instantly rotates the VE around the participant, after a short fade in. This technique is inspired from the *Freeze-turn* [18] and the *Bookshelf* technique [19].

4 REDIRECTION SYSTEM

To activate the distractor at the correct time, it is necessary to know when the player is nearing the edge of the physical area. A safe area (2.05 m × 2.05 m) is defined within the total available play-area. When users leave it, the distractor appears. It will stay active until the user is redirected optimally even if they re-enter the safe area again (see Figure 3 for the activation conditions).

The yaw rotation is calculated as:

$$\theta_{virtual} = \theta_{real} + \theta_{real} * gain$$

with $gain = -0.3, 0, +0.3$. When the value is zero no reorientation occurs. The sign of the gain depends on the direction of the head rotation. A negative sign indicates that the camera is rotating by a smaller angle in the VE than in reality, vice versa a greater angle. The exact amount that the camera should be rotated is calculated based on player position and direction of the instantaneous delta rotation. The player is guided in the direction that makes them turn away from the boundary the quickest. This is done by calculating the angle between the center-player and the target location. If this angle is negative or greater than 180°, the extra rotation is negative, otherwise positive.

5 USER STUDY

We performed a within-subject user study with the aim of evaluating the performance and user experience aspects of the distractor techniques. Each technique was shown only once to each user. The order of presentation was counter-balanced. We collected quantitative data such as task completion times and other derived measures (activation time, time and distance estimates).

5.1 Participants

We recruited twenty-three *participants* aged between 20 and 57 ($M = 31.26, SD = 13.00$; 7 female, 16 male), with low self-reported experience with VR technologies ($M = 2.61, SD = 1.75$, out of seven) and infrequent use ($M = 2.09, SD = 1.08$).

Participants filled Kennedy's Simulator Sickness Questionnaire [5], Slater-Usoh-Steed's presence questionnaire [17], and a custom set of closed and open questions, after each technique. Additionally, after concluding the experimenting, they filled a final questionnaire on the noticeability of the redirection and overall preference.

5.2 Taks

The *task* consists in reaching a target area in a large futuristic hangar, with each technique. The target is clearly visible from the starting location and marked by a light beam. It is located at a distance of 30 m from the starting location. Additionally, participants were instructed to stop when the distractor appears and only continue with the task when it disappears again. However, camera updates were not stopped.

5.3 Apparatus

The interaction they have with the distractor is different each time. The VE was designed using Unreal Engine 4.20. Participants used a HTC Vive with a TPCast add-on, which enables wireless use of the headsets. It requires that users carry a 20 100 mA h battery in a strap worn over their waist. We used a PC with an nVidia GTX 1070.

6 RESULTS

In the following we report the main results from the data we collected. Due to data failing the assumption of normality, both quantitative and qualitative data were analysed with Kruskal-Wallis non-parametric tests. Exceptions are specified in the following.

6.1 Quantitative Data

Total trial times can be seen in Figure 4. Kruskal-Wallis shows a significant difference between conditions ($p < 0.01$, $\chi^2(3) = 52.92$). Post-hoc pairwise Wilcoxon signed rank tests shows that *Stop and Reset* was faster ($M = 81.15$ s, $SD = 28.04$ s) than the three other conditions. Among the continuous interactive distractors, the fastest was *Touching* ($M = 244.60$ s, $SD = 39.10$ s), followed by *Interacting* ($M = 251.19$ s, $SD = 47.51$ s). *Interacting* was significantly slower than *Looking* ($M = 222.75$ s, $SD = 36.40$ s).

There was a significant difference in the relative proportion of time in which distractors were active ($\chi^2(3) = 21.965, p < 0.01$). The discrete *Stop and Reset* distractor was active for significantly less time (19% compared to 72-76% of the continuous distractors).

The time participants were looking at the distractors was also estimated by measuring the amount of time each distractor was within an angle of 90° from the user, since the headset used did not have an embedded eye-tracker. We found significant differences ($\chi^2(3) = 52.92, p < 0.01$) when comparing the percentages of time users were looking at the distractors when they were active. with *Stop and Reset*, participant looked at the distractor 98% of the time it was active, significantly more than the three other techniques. Pairwise comparisons also show that participants looked significantly

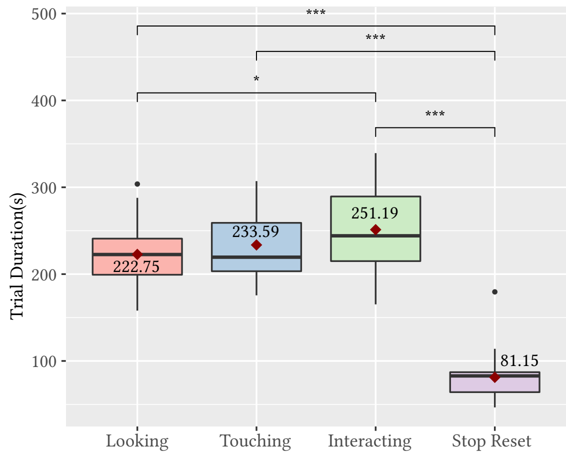

Figure 4: Trial duration in seconds, per condition. One * indicates significance at $p < 0.05$, three at $p < 0.001$.

less ($p < 0.01$) at the *Looking* distractor (93%) than the *Interacting* distractor (96%).

6.2 Questionnaires

The SUS questionnaire [17] was analyzed by counting the number of 6 and 7 answers. A non-parametric Kruskal-Wallis test did not find significant differences ($p = 0.38$) between the three techniques, nor in terms of SSQ Total scores ($p = 0.65$). *Stop and Reset* received 5.17, *Looking* 7.34, *Interacting* 6.81, and *Touching* 6.83.

Regarding the noticeability of the redirection techniques, the Cochran's Q test identified significant differences ($Q = 17.5, p < 0.01$). Pairwise comparisons identified *Stop and Reset* to be significantly more noticeable than the continuous redirection techniques ($p = 0.01$ with *Looking* and *Interacting*, $p = 0.04$ with *Touching*), due to its in-place teleportation with 87% participants noticing the manipulation. The least noticeable interactive technique was *Interacting* (39%), followed by *Touching* (52.2%). When using the *Looking* technique, 47.8% of the participants noticed the redirection. These results were obtained while keeping the Chaperone boundary system active, whereas in VMotion it was disabled [13].

We also asked each participant to estimate both the distance walked and the time elapsed. While there were no significant differences in terms of distance ($p = 0.85$), we found significant differences ($p < 0.01$) in terms of time estimation. Participants estimated the *Stop and Reset* technique to take a mean value of 206 s, almost three times as much as the average completion time. Conversely, the estimated times were: *Looking* 339 s; *Touching* 372 s; *Interacting* 391 s. While closer to the actual elapsed times, these were still about 50% longer, as opposed to 150% longer estimates for *Stop and Reset*.

At the end of the experiment participants were asked to choose which techniques they preferred. *Interacting* was preferred the most (9 preferences, 39.1%) followed by *Touching* (7, 30%), *Stop Reset* (4, 17.4%) and *Looking* (3, 13%). However, Cochran's Q test did not identify significant differences between these values ($p = 0.27$).

7 DISCUSSION AND CONCLUSION

In this work we explicitly focused on understanding the impact of distractor interactivity when redirecting users in small spaces. While discrete distractors such as "Stop-and-Reset" provided the shortest mean task completion times, our results indicate that continuous distractors have an advantage in terms of decreased noticeability and user focus. Participant #15 said *"More concentration on the ball, less on the environment."* A discrete orientation reset represents a *break in presence* (P14: *"Very weird to see the image jump."*), whereas a distractor that is contextually appropriate is better received, which is in line with prior results. P21 said: *"I seemed to walk in a much bigger space than the size of the room."* Although the differences in terms of user preference were not significant, the least interactive distractor, *Looking*, was preferred by the lowest number of participants (3), as opposed to *Interacting*, the most complex, which received the highest number of preferences (9).

Future research can focus on understanding whether the potential for more intensive forms of redirection increases with the level of complexity of the interaction. Another potential direction consists in exploring the noticeability thresholds of higher gains (we used a more conservative value of 0.3, versus the 0.5 used in VMotion [13]) or other types of changes to the VE.

The major limitations of redirection through distractors is that the specific type used is often dependant on the nature of the VR experience. However, we think that it is possible to generalise the *interaction metaphor* rather than the specific appearance of the distractor. While an orb might be more appropriate for futuristic scenarios, the metaphors of touching it or playing a combination game can be adapted to use other appearances. For example, a virtual character handing out flyers in a contemporary urban setting as an analogous of the *Touching* distractor, and an enemy fight based on attack/defence moves as analogous of *Interacting*. However, the repetivity of these distractors should also be studied in the context of longer immersion times.

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