Bouncing Ball Traversal: A Target-Based Travel Technique For Vertical Travel

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ABSTRACT

We present Bouncing Ball Traversal (BBT), a novel and playful virtual locomotion technique developed to explore vertical traversal in Virtual Reality (VR). BBT allows users to throw a virtual ball and teleport to its landing spot after a configurable number of bounces. Though not designed to directly solve limitations of existing traversal methods, it offers an alternative approach that may support vertical movement and obstacle navigation. We evaluated BBT through a testbed study with 10 participants across four VR environments, collecting performance data and subjective feedback on task load and cybersickness. Results indicate BBT is fun, engaging, and intuitive, with low cybersickness scores and manageable cognitive load.

Index Terms: Human Computer Interaction—Virtual Reality—Virtual Locomotion Traversal

1 INTRODUCTION

In Virtual Reality (VR), users are often required to traverse in virtual environments using specifically designed techniques, for specific tasks. This is due to limitations such as the physical space available, the distance required to be traveled in the virtual environment, and the speed in which the user can cover these distances. There exists many different types of these techniques in VR, each separated into specific classifications dealing with these limitations in some way shape or form. [15]

One of the more widely used traversal techniques in VR applications, is the target-based traversal technique *Teleportation* [15, 19]. Commonly teleportation in VR requires the user to point with a ray shooting out in front of the controller, to a specific point in the environment. Then by pressing a button on the controller, the user is transported to this new location. [19] The preference for this traversal technique stems from its benefit of producing lower cybersickness than other established traversal techniques [1, 15], which is beneficial as VR sickness is a major concern for VR [2, 6]. However, compared to more natural developed relationships, teleportation is reported to have less user presence than walking metaphors [21], despite being less overwhelming for users than walking directly [9]. Other issues are also prominent with teleportation as a traversal technique, such as preservation of spatial orientation in difficult and complex scene settings [13], alongside vertical and obstacle travel limitations [17, 19]. To account for these issues, the following paper covers the design and evaluation of a new *Virtual Locomotion Traversal* (VLT) [1] technique, that we have named *Bouncing Ball Traversal* (BBT). By applying a testbed evaluation approach [15], we can determine the usefulness of our traversal technique, in various scenarios, and see if users find it interesting and useful for traversing in VR.

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2 RELATED WORKS

The following section will cover the theory and challenges within *Target-based traversal techniques* and *Vertical travel*.

2.1 Target-Based Travel Techniques

When it comes to Target-Based Travel Techniques, the goal often revolves around the task of users moving the viewpoint position within a virtual environment. Here there is more emphasis on getting to the endpoint, and less so on doing the actual motion to reach the destination. [15] There are many ways in which users can specify where to travel. Teleportation is but one example of target-based traversal, yet other examples include selecting an object as a target location [8] or placing a marker in the environment (such as positioning oneself on a map) [25]. While these methods can be very efficient and easy to use, the primary flaw in these techniques revolves around the aspect of maintaining spatial orientation [13, 15]. This lack of spatial orientation can be alleviated somewhat by having continuous movement from the starting point to the endpoint. However, if this continuous movement gets under the user's control it can increase cybersickness. Transitioning effects such as the blink effect can therefore be applied to make this continuous movement, as it happens rather quickly, but still provides information about how the user has traversed to their target destination. [15]

2.2 Vertical Travel Techniques

When it comes to traversal methods that explore the vertical plane, solutions tend to be either in regards to directed steering metaphors, like flight [15, 24], or more natural and realistic methods like ladder climbing [14, 15, 22, 23]. However, when it comes to target-based traversal methods like teleportation methods, they are usually focused on traversal in the 2 dimensional space (horizontal plane) [15, 17]. This is due to challenges such as: selecting the depth in which you want to travel, as well as the relative placement of the user at the teleportation point [17]. Despite these difficulties, the idea of designing a VLT that enables vertical traversal through a target-based travel technique remains a compelling area of research. In response, we present a new, engaging traversal method that aims to address these issues.

3 BOUNCING BALL TRAVERSAL

To explore the BBT technique further, the following section will firstly highlight two VLT's that inspired the idea behind our technique. The section will then describe the user interaction with the Bouncing Ball, using task decomposition, before illustrating scenarios in which the technique can be beneficial for users, when applied in certain virtual environments.

3.1 VLT Inspiration

A study by Di Luca et.al [7] devised the Locomotion Vault, a tool visualizing various locomotion techniques, with the goal of creating a platform that aids analysis and innovation of new locomotion techniques. From browsing this Locomotion Vault, and discussing the various VLT's, two traversal techniques emerged within our interest. The first of these traversal techniques is called *Teleport Throw*, a technique revolving around the concept of the user throwing an

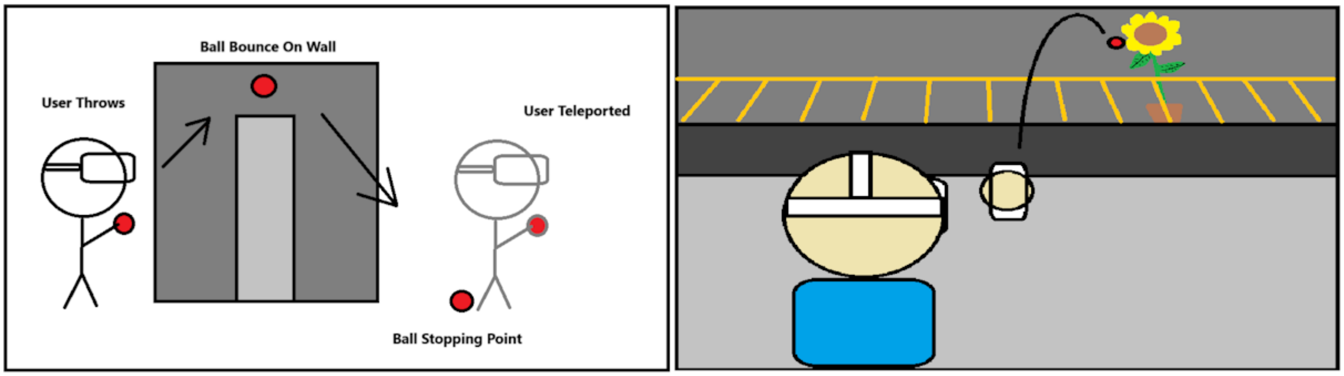


Figure 1: Concept illustrations of vertical and obstacle navigation scenarios using BBT

object or shooting an arrow to move instantaneously to the location where the object or arrow lands. The second traversal technique is called *Head Bowling* in which a user traverses by grasping their head (making the camera part of the hand movement), throwing it, and then pressing a button to teleport. Primarily the Teleport Throw technique had our interest due to its capabilities of giving a more varied teleportation range (both horizontally and vertically). With the concept of a ball in mind from the Head Bowling technique, we thought of bouncing balls and the fun interaction that could come from bouncing them up against walls and ceilings. Combining the idea of Teleport Throw with the bouncing aspect of bouncing balls led to the development of our proposed VLT.

3.2 Task Decomposition

To describe the process of traveling with the bouncing ball, the following task decomposition will chronologically describe the steps of utilizing the ball to traverse in the virtual environment. This task decomposition takes basis in the taxonomy of travel techniques focusing on level of user control [15].

Start To Move: When the user decides that they want to traverse within the virtual environment, the first step requires the user to grab the ball, located on the floor in the first scene.

Grab the Ball: To do so they will have to navigate a hand towards the ball, and then, when their hand is at the balls position, press the grip button on the right controller to attach the ball to the right hand. This uses a grasping metaphor, a natural technique between the relationship of the ball and the user [15].

Adjust/Check Ball Bounce Value: In this state of having the ball ”gripped”, it can now be adjusted with a magical technique in the amount of times it is going to bounce before teleportation. [15] These can be adjusted via the ’X’ and ’Y’ Buttons on the left controller, and the number of bounces is represented as a number on the ball itself.

Orientate Towards Desired Travel Position: Once the user is satisfied with the amounts of bounces, they can use physical locomotion to orient themselves towards the position they want to traverse to. This requires the user to turn and position themselves in real life, which in turn positions them in the VR environment via naturalism [15].

Throw Ball Towards Desired Position: Once oriented towards the desired traversal position, the user can throw the virtual ball by engaging in a throwing motion based on a combination of discrete selection in the VR environment. [15] By releasing the grip button at the end of the throwing motion, the ball is released from the grasp and will start moving in the virtual environment. Causing a real world motion to be translated to the VR game world [15].

Teleported After Ball Bounce Condition: Once the ball has bounced the specified amount, and hits the ground, the user will be teleported to that position, while preserving their world space orientation.

Stop Moving: The user is now at the new position and can restart the process whenever they again need to move. However after each teleportation, the ball is repositioned to the bottom of the left controller. This is a magical translation done to preserve user knowledge of where the ball is in the VR space at all times [15].

3.3 Use Case Scenarios

When looking at regular teleportation as a traversal technique in VR, often times people are limited to the floor level horizontal plane [17]. This means that teleportation in the vertical plane often isn’t possible, meaning that environments consisting of various floor levels, will require the user to teleport to stairs before being able to get to their desired destination (if that destination is above them). With the integration of the BBT technique, users will be able to more efficiently get to destinations located above them. Figure 1 provides visual insight to the use of BBT for vertical travel.

Aside from vertical traversal, areas with lots of obstacles can also be more easily navigated by using the ball. In teleportation, users often have a ray to signify the position they will spawn after teleporting [5, 17]. However, when encountering walls the ray cannot traverse past these walls. Using the ball, users will be able to quickly navigate past walls, and again, more quickly be able to get to their desired destination. Figure 1 shows a scenario in which the ball would be useful in getting past obstacles.

Combining these two aspects makes for an interesting traversal tool that can be more efficient in certain scenarios, compared to regular teleportation. We believe that the aspect of having to calculate and analyze the path of the ball before throwing, adds a level of fun to the traversal process, making it more interesting for users to utilize. Users getting comfortable with the tool, might also begin to utilize it in unique and interesting ways (trick-shot potential), which can make the BBT more than just a traversal technique.

4 Evaluation

To evaluate our proposed VLT, the following study makes use of a testbed evaluation approach [15]. Since we want to understand the detailed performance characteristics of our traversal techniques,

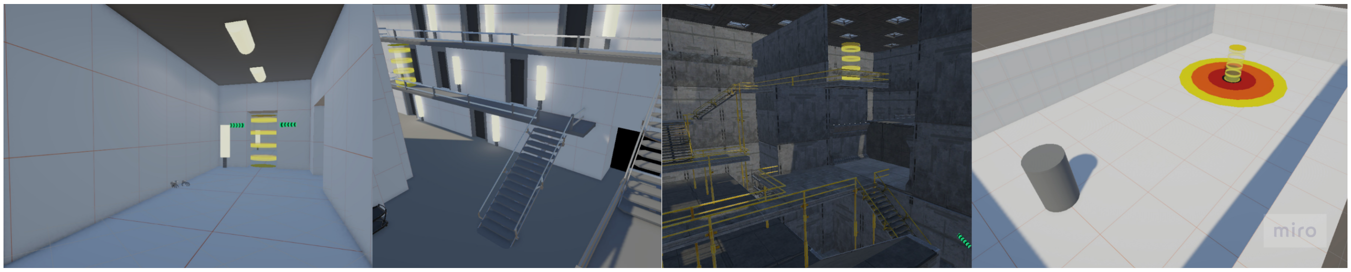


Figure 2: Visual overview of the various environments created to test the BBT technique.

the testbed evaluation approach can provide a quantitative basis for choosing this technique, by analyzing it across a range of tasks, environments, and users in the application.

4.1 Initial Evaluation

When the prototype had been developed, a stress test on the system was conducted. The test recruited participants experienced in VR to see if the system would be intuitive, and perform consistently across tests with unbiased input. 8 participants were part of this evaluation and were found at Aalborg University. Participants completed two questionnaires after each test. One regarding cybersickness in VR and another regarding task load. From this initial evaluation, we were able to have an informal evaluation [15] where we could discuss our current structure of the application, as well as our plan for our testbed evaluation, with the users. From these discussion, we would then write down some of the feedback that we saw as beneficial for improving the design of our VLT.

4.2 Outside Factors

We have created 4 task-specific virtual environments (see Figure 2), each reflecting different challenges in VR traversal. These areas are primarily related to the *primed search* task [15], where the user knows the position of the target or a path to it in advance. The primed search task was selected due to the fact that these selection-based travel techniques are discrete in nature, and are therefore better suited for this type of task [1,4]. Wayfinding cues are implemented in each area to direct the users search, providing them with information of their target position. While primarily focused on the primed search task, various other travel tasks are explored in each area:

Area 1: The first area is an obstacle course, with many corners and walls, where users have to navigate through waypoints until they reach a goal. This area looks at the task of *amount of curvature or number of turns in the path* [15], exploring how well users utilize the BBT to turn corners and reach their destination.

Area 2: The second area explores the vertical travel capabilities of the VLT, by having the user reaching waypoints located on various floors above them. This somewhat explores the task of *number of DOF required for the movement* [15]. We use this area to explore how effective users are at utilizing the bouncing ball capabilities, to travel in the vertical space. In other words, explore how users utilize the traversal technique, when more DOF's are required to reach the specific goal.

Area 3: The third area is a combination of the first two, looking at how well users perform in a more general context, and see how they behave when both factors happen at the same time (turns in the path + number of DOF required for the movement).

Area 4: The last area is a simple precision area where users will have to hit the center of a target with the ball. With this we can explore the task of the *required accuracy of the movement* [15] to see how well users are in throwing, and actually hit their desired destination. It is explored if users tend to overshoot, or undershoot their desired destination, and how quickly they can recover from the error.

4.3 Performance Metrics

For the testbed evaluation, certain performance metrics are gathered during and after the VLT test, to understand the general user task performance of BBT.

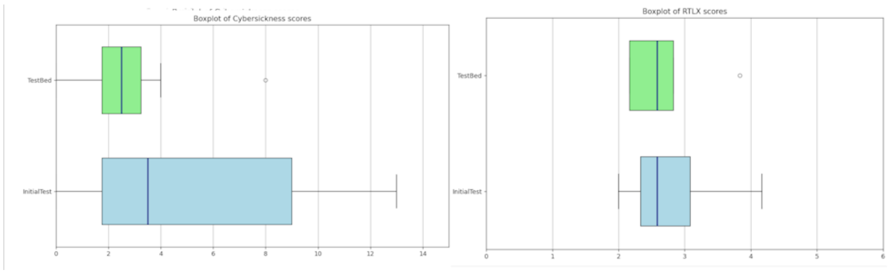
System Performance Metrics: For system performance metrics, Frame-rate (FPS) is the most important measurement. FPS is of interest due to the BBT throw implementation being reliant on the applications FPS performance. Thus we wanted to see if performance was consistent throughout tests. FPS is also connected with Cybersickness, regarding latency in the visual display [15]´, making it valuable when exploring cybersickness.

Task Performance Metrics: Certain task performance metrics are logged during the play sessions. These task metrics' purpose are to provide insight into the player performance, which we can correlate with the questionnaire scores. The task metics used, assess the participant's interaction with different aspects of the VLT and can be divided into "task specific data" (data metrics concerning the scene set-up), and "user specific data" (data metrics concerning the users interaction with the VLT element directly). Primarily, the aspects regarding the speed in which the user can navigate through the various areas, is the key component we want to focus on when analyzing the results. This is due to the fact that direction and speed are two fundamental components of VLT's and should therefore be analyzed to understand the effectiveness of ones VLT [1,18].

Subjective Performance Metrics: Subjective performance metrics are also used during the test, This is done by using questionnaires to provide us with insight on our traversal technique subjectively.

Cybersickness Questionnaire: Since our prototype intends to be an iteration on VR teleportation and it often causes low cybersickness, as mentioned in the introduction 1. Using a questionnaire to measure cybersickness for comparison seems ideal. For this we use the CSQ-VR Cybersickness Questionnaire. Which is a questionnaire designed to measure the presence and intensity of cybersickness in VR on a 7-point Likert scale from 0 to 6, consisting of six questions on 3 sub-scales [12].

Task Load Questionnaire: To support our task performance metrics, a mental task load questionnaire is also chosen. For this we will use the raw NASA TLX (RTLX) questionnaire. [10,16]. RTLX covers six sources of workload areas, being mental, physical, temporal,



USER	loggedFPS	bounceAmount	totalBallThrows	lastThrow
AVG User_1	61,38627	2,220727	58	7,034279
AVG User_2	61,0232	1,90232	91	5,06709
AVG User_3	118,3062	2,641677	60	6,983728
AVG User_4	70,80952	1,679487	54	5,343651
AVG User_5	61,07513	2,170678	101	6,687457
AVG User_6	71,67414	2,399077	84	10,81552
AVG User_7	67,66494	2,498893	89	6,136971
AVG User_8	73,17892	3,058027	53	14,93689
AVG User_9	86,39097	2,592258	43	6,842653
AVG User_10	82,74166	1,922126	54	9,620302

Figure 3: Overview of results obtained from the questionnaires and metrics. On the left, is shown a boxplot of the scores from the CSQ-VR questionnaire. The Cybersickness score does go from a scale of 0-36, but is scaled down for better comparison. In the middle is a boxplot of the RTLX scores, and on the right are the task performance metrics, averaged across all virtual areas, for each participant. The 'lastThrow' column, highlights the average amount of seconds users spend between throws.

effort, performance, and frustration [16].

4.4 Testbed evaluation

After having gone through our initial evaluation and established our taxonomy, outside factors, and metrics of performance, the testbed evaluation is performed. For this we recruited 10 participants at Aalborg University to play through our VLT prototype and answer the two questionnaires at the end. Relevant task metrics were logged through each play session, and an additional question provided feedback regarding to whether users found the BBT to be a fun technique for traversal in VR.

5 Results

The following section will visualize and explain the results from our evaluation. Results are separated in two sections, the first covering the initial evaluation results, while the second covers the main Testbed evaluation.

5.1 Results from initial evaluation

From the first study where 8 participants took part, results from the cybersickness questionnaire showed that the application scored well on all metrics, with the worst performing score concerning "disorientation", having a score of a 1.625 average out of 6. This, combined with the total score for cybersickness having an average being 5.375 out of 36, shows that participants in general did not experience many symptoms. In the RTLX questionnaire, the questions which scored worst attained to mental activity, with both "mental and perceptual activity" and "mental and physical work required" scoring 3.125 out of 5 on the scale. This means that some level of workload was required for users to engage with the BBT technique. Task performance metrics were not logged in this evaluation.

5.2 Results from testbed evaluation

During the testbed evaluation where 10 participants took part, results from the cybersickness questionnaire showed better results compared to the initial test evaluation. Having "disorientation" still being the worst performing category with a 0.7 average out of 6, average scores ended up being 2.5 out of 36, making all 6 categories perform better compared to the initial test evaluation. Furthermore, the RTLX questionnaire in the testbed evaluation also performed better, with 5 out of 6 categories scoring lower and the worst performing category being a 3.0 of 5 for "mental and perceptual activity". although still lower, it is seen that some level of workload is still required for users to engage with the BBT technique.

Compared to the initial evaluation, task performance metrics were logged during the testbed evaluation, to see how well users performed in the various environments. In *Area 1* users on average spent 135 seconds, with approximately 12 seconds between throws. Average throw amount was close to 12 throws, and the average bounce amount setting was approximately 3 bounces. In *Area 2* users on average spent 134 seconds, with approximately 8 seconds between throws. Average throw amount was 14 throws, and the average bounce amount setting was approximately 2 bounces. In *Area 3* users on average spent 289 seconds, with approximately 6 seconds between throws. Average throw amount was 39 throws, and the average bounce amount setting was approximately 2 bounces. Lastly in *Area 4* users on average spent 24 seconds, with approximately 5 seconds between throws. Average throw amount was 4 throws, and the average bounce amount setting was approximately 1 bounce. The logged data shows no indication of having affected the questionnaire scores.

Regarding the feedback for the prototype, all 10 participants answered having a positive experience using the traversal method to varying degrees.

6 Discussion

Our evaluation showed that the BBT technique is a viable, engaging and especially fun alternative to traditional teleportation, in primed search tasks. It performed well in both vertical and obstacle-heavy environments, with users reporting low cybersickness, manageable task load and high perception of success. However, limitations include a bug affecting throw accuracy and a small participant sample, which restricts generalizability. While the design of our VLT proved intuitive and offered greater spatial flexibility than standard teleportation, it came at the cost of precision. Throwing in VR remains inherently difficult due to hardware limitations, such as loss of tracking when arms exit the headset's field of view [11], and the inability to simulate realistic rolling releases, creating a disconnect between physical and virtual throwing [20]. This gap can make the interaction feel less natural and harder to master.

Future work should explore more tasks like exploration, naïve search, or maneuvering, and compare it to other VLT's to see if it overcomes some of the challenges within target-based traversal techniques [1]. Additionally, the metric of immersion and presence should be incorporated to quantitatively assess whether our proposed VLT makes users more present and immersed in the virtual environment, compared to other target-based traversal techniques (like teleportation) that tend to score low in this regard [3, 19]. As for the current implementation, refining the interaction design, adding visual feedback for ball trajectory and waypoints, and resolving technical issues are key steps toward improving the experience of BBT. Overall, Bouncing Ball Traversal introduces a novel and intuitive approach to VR locomotion that encourages exploration and vertical movement, paving the way for alternative interaction designs.

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