A Supernatural VR Environment for Spatial User Rotation

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Abstract

VR environments with supernatural properties which expand or replace the laws of physics could be used to understand how the brain organises and interprets sensory stimulation. We built an application with a supernatural room that allows users to walk up the wall and on the ceiling. During preliminary tests, we optimised the application so that it rarely causes cybersickness. User reports and observed user reaction such as swaying indicate that users accepted the rotation as a self-rotation, as opposed to an animated rotation of the room around the user. Therefore the application is viable for future studies on spatial orientation, pathfinding and cognitive maps.

Index Terms: Human computer interaction (HCI)—Interaction paradigms—Virtual reality.

1 Introduction

As virtual environments are not bound to the laws of physics, they provide a framework for implementing supernatural environments that expand or even replace physical laws [10] [5]. These supernatural properties create illusory distortions of perception which can be used to understand how the human brain organizes and interprets sensory stimulation [8].

One well-researched example for supernatural environments in VR is "impossible rooms" that break the laws of Euclidian physics [4]. Another one would be an environment with changed gravity that allows users to walk on walls and ceilings. This environment could be used to test user adaption to rotation around a horizontal axis and its influence on spatial orientation, cognitive maps and path finding [9] [2].

For this purpose, we built a VR environment that allowed us to manipulate user rotation. One factor that could make or break the application would be if the user rotation caused cybersickness in users [7]. To test for this, we conducted two preliminary test phases: During an alpha phase we tested the room with about 150 users, and constantly improved parameters, such as rotation speed, according to user reaction. During the beta phase we carried out tests with different movement methods to see if they had an influence on motion sickness during rotation.

Another problem could arise if users would not perceive the rotation as their own, but just as an animated rotation of the room around the user. To avoid this, during the alpha phase we constantly added markers to the environment that provided opportunities for the user to experience illusory self-rotation.

2 Implementation

The rotation application was built in Unity 3D. It consists of three components: the Movement Controller (MC), the Anchor, and the Rotation Component.

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Figure 1: The virtual room and the ramp's rotation colliders.

2.1 Movement Controller

As rotating the Unity character controller around a horizontal axis is not supported, we tried to rotate the room instead. But this interfered with the Unity physics and other systems. Rigid body methods to rotate the character controller could not be adapted for VR. For that reason, we built a customised Movement Controller. This gave us control over collision and movement on walls and ramps, no matter the rotation angle, and allowed us to directly evaluate motion vectors.

2.2 Anchor

The Anchor serves as "administrator" and interface for movement, and can also integrate different movement types. Using the MC, the Anchor controls movement to avoid collider penetration. When the user tries to walk through objects or walls, the Anchor shifts the user slightly to avoid penetration. The Anchor also abstracts the HMD to allow portation to different hardware, including other VR systems and 2D display use.

2.3 Rotation Component

The Rotation Component detects collision triggers which initiate calculation and user rotation. For rotation, it calculates the new direction of the up-vector from the direction of the colliders, and implements it at 9° per second.

3 Rotation

Rotation is triggered at the four 45° ramps which are placed at two opposing sides of the room, two on the floor and two at the ceiling. Each ramp triggers a 90° user rotation. During a full journey, from floor to wall to ceiling to wall back to the floor, the user experiences a 90° rotation four times, completing a full 360° rotation by the end of the test.

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Each ramp contains two colliders, so that it can be used for both "up" and "down" rotations. When users step on the ramp, they pass the first collider. Only contact with the second collider triggers the rotation of the movement controller.

When the user steps on the ramp, animated movement speed is slowed down by factor 0.3 to avoid a combination of animated movement and animated rotation that caused an increase of cybersickness in alpha test users. The user is rotated around the horizontal axis for 10 seconds with a speed of 9° per second. The pivot point is in the "feet". After leaving the ramp, the user can proceed along the wall with normal translation speed.

4 Environment

The earliest test environment was a simple box with a checker pattern on all 6 walls. As this repeating pattern inhibited spatial orientation during rotation, we built a "loft" room with a set of furniture. To further increase orientation, the floor, walls and ceiling had distinct and easily identifiable patterns, i.e. a wood texture for the floor, striped wallpaper for the walls, and a plain white ceiling. Furniture and other assets were placed as distinct landmarks.

Both the vertical stripes of the wallpaper and the vertical furniture were implemented to increase orientation during rotation, by clearly indicating a vertical axis parallel to gravity. To "prove" that the room did not rotate, we placed light weight objects such as a paper umbrella and an animated cat on the floor as "indicators of gravity".

5 Preliminary Results

During our preliminary tests, users were asked to walk towards one of the ramps, "climb" it to trigger the rotation, walk up the wall, again trigger the rotation with the next ramp, walk along the ceiling towards the hanging lamps, and then to return to a landmark on the floor.

After continuous improvements during the alpha and beta phase, all components run stable and function seamlessly. Ramps and collision triggers can be easily adapted for different environments by simply changing their position. The Anchor abstracts the HMD which allows building extensions. For testing purposes, single parameters such as speed, and presets can be adapted. More iterations are necessary to prepare the MC prototype for use in complex environments.

Future improvements include a better collision solution and a better foot tracking with trackers attached to the feet instead of simple head tracking. This would stabilise height changes by head movements of the user on the ramp.

After adapting rotation speed, surprisingly few alpha and beta testers reported typical cypersickness symptoms during or after rotation. Even when "stress testing" with different movement methods, the occurrence of cybersickness symptoms was low: of 21 beta testers 89 % showed no symptoms at all, 8 % had minor symptoms, and only 3 % had moderate symptoms.

Rotation was well accepted by a large majority of users.

Several testers showed minor problems with balance, but nobody fell. Swaying and trying to regain balance can be interpreted as an indicator that users felt they were self-rotating, as opposed to a simple animated movement of the room around the user. As the simulation of self-rotation was one of our goals, a loss of balance can be seen as a positive result.

Swaying as a reaction to rotation could be observed during the rotation itself but not when users walked on the ceiling. Nobody reported a physical upside-down sensation while "hanging" from the ceiling. This observation can be explained by the fact that proprioception integrates both vestibular and haptic information with visual information [1]. Specific retinal and cortical cells in the eye are primed to detect a frame of reference that is parallel or perpendicular to gravitation [6]. As such, the field of vision forms a body-centered frame of reference for orientation. Moving or swaying walls can induce swaying in a test subject, as visual information about verticality is used for postural control [3].

This means that when the whole frame of reference, consisting of all environmental angles that are parallel or perpendicular to gravity, is tilting, the user seems to read this as self-movement and adapts posture accordingly. But when the user walks on the ceiling, the frame of reference is parallel and perpendicular to gravity again. Because of that, the visual cues can no longer override (physical) haptic and vestibular information about gravity, which the user also perceives during the test. This explanation is confirmed by the fact that swaying increased when alpha and beta test users looked in the direction of the room during rotation, so that the changing angles were clearly visible to them.

6 Conclusion

We built an easy to use VR application to simulate walking up walls and on the ceiling, including simulated user rotation around a horizontal axis. After adapting rotation speed, rotation causes little to no cybersickness symptoms.

Users show physical reactions, such as swaying, during rotation, but not when walking on the ceiling. This can be explained by the fact that changing angles in the visual frame of reference influence proprioception and induce posture adaption [1] [6] [3]. The influence of these optic cues on proprioception stops when users reach the ceiling, i.e. when all angles in the visual frame of reference are again parallel or perpendicular to gravity. The swaying also indicates that users perceive the simulated rotation as self-rotation and not as a simple animated rotation of the room around the user.

As our application causes very little cypersickness, and as it triggers physical reactions that indicate a perception of self-rotation, it can be used for further studies on spatial orientation, cognitive maps and pathfinding within a supernatural environment.

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