Infinite Walking in Three Dimensions in Virtual Reality

A Shopping Mall Simulator Game

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ABSTRACT

In virtual environments, users can move almost infinitely while actually staying within a small area in real space. Several techniques such as Infinite Walking and Redirected Walking have already been developed for this purpose, but in order to overcome their respective limitations, several of them must be combined with visual effects and tricks to create the impression of a realistic environment and realistic movement. In this paper, our graduation class presents the prototype of a shopping mall simulator game realizing infinite motion in 3D on 639 m² within a 5 x 5 meter VR sensor range, even allowing the player to move freely on multiple floors of a beautifully designed shopping mall.

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CCS CONCEPTS

• Human-centered computing ~ Human computer interaction (HCI) ~ Interaction paradigms ~ Virtual reality

KEYWORDS

Virtual Reality, Infinite Walking, Redirected Walking

1 Introduction

To achieve the goal of more realistic and more immersive VR experiences, simulating the possibility of moving as freely in VR as in the real world can play a key role. In fact, virtual environments do not necessarily have to be limited to the space available in reality. Theoretically one can move almost infinitely within a limited sensor range in physical space using techniques such as Infinite or Redirected Walking.

Our graduation class of 2020 of the "Virtual Realities" B.Sc. degree course was given the task of realizing infinite motion in 3D within a 5 x 5 meter VR sensor range, allowing the player to move freely, without using teleportation, on multiple floors of a shopping mall in a prototype for a shopping mall simulator game. The prototype was also required to comprise at least one haptical element that the player was required to interact with. To accomplish this task, our class had to combine numerous techniques, tricks, and visual effects...

2 Background

To achieve the goal of more realistic and more immersive VR experiences, simulating the possibility of moving as freely in VR as in the real world can play a key role. Letting a user walk almost infinitely though a virtual environment while being restricted to a small movement area, however, is not new, but also not simple. Restrictions are usually imposed by both the available VR equipment and the limited movement area. To overcome these restrictions, several techniques such as Infinite Walking [1] and Redirected Walking [2] are known, but they all have their respective limitations, among them the limitation of movement to a plain area.

2.1 Infinite Walking in Limited Space

Introduced by Vasylevska et al., Infinite Walking relies on the procedural generation of layouts for virtual spaces [1]. Such spaces overlap each other in VR to give the user the impression of walking through multiple bigger rooms or one long corridor, while actually staying inside the available movement area. The layouts can be generated dynamically at runtime.

2.2 Redirected Walking

Redirected Walking [2] uses various sophisticated algorithms for locomotion in VR [3]. As soon as a user approaches the edge of a movement area, the algorithm manipulates the displayed scene to redirect her: While the user has the impression of walking in a straight line, she unknowingly walks at an angle or circle. The algorithm ensures that the user walks at an angle that depends on the size of the movement area, thus ensuring that the user never leaves it.

2.3 Active/Passive Walking

Active/Passive Walking is not a method based on scientific findings, but a distinction we made to define areas in the virtual space in which a) the user (actively) moves by physical motion or b) the user is (passively) moved by other means.

For Passive Walking, we analyzed several means common in real life to move people while they stand still or continue moving, e.g., means such as passenger conveyors at airports, elevators in multi-floor buildings, and escalators in shopping malls. Some of these means allow users to switch from one floor to another, and thereby, from one environment to another, without walking. Ultimately, this enables passive movement in the third dimension.

3 Movement and Interaction

Our game prototype combines Infinite Walking and Active/ Passive Walking with visual effects and tricks to create the impression of realistic movement inside a realistic environment, that is, our virtual shopping mall. While the first three floors of the shopping mall employ Active/Passive Walking, the fourth floor uses an additional procedural level generator to create corridors and offices on the fly. On all floors, the user can and must interact with real buttons, experiencing haptic interaction and feedback.

The player can move through a shopping mall and explore its four floors of shops and offices at will. Fig. 1 shows the architecture of the first three floors of the mall. The areas the player can reach and explore are marked with a green floor color. Some areas such as closed shops are only visible to, but not accessible by the player. The size of the respective areas is listed in Table 1. Within a movement area of only 5 x 5 meters, the architecture of our mall comprises three floors with four open shops, six closed shops and a fourth floor with a virtually unlimited number of corridors and offices.

Table 1: Size of the virtual shopping mall

	total area	explorable (Passive Walking included)	accessible by foot
total area	639 m²	181 m²	149 m²
entrance hall	100 m²	50 m²	45 m²
1st floor	195 m²	25 m²	20 m²
2nd floor	71 m²	25 m²	20 m²
3rd floor	123 m²	25 m²	20 m²
3 escalators	3*25 m²	3*22 m²	3*22 m²

Figure 1: Architecture of the first three floors of the virtual shopping mall

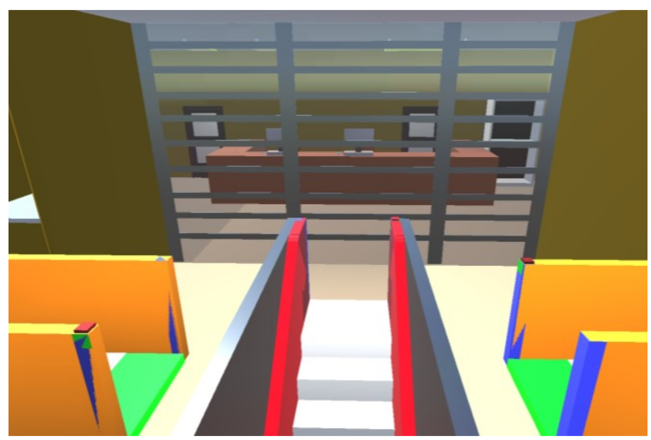

Figure 2: In-game screenshot: Riding the escalator to the second floor, looking into a closed shop. The buttons are virtually represented at the ends of escalators and conveyers.

Within any room, the player can move freely. To switch between the floors, the player is provided with escalators (see Fig. 2). While this is a natural way of moving from one floor to another without walking, Infinite Walking proved to be inadequate to let the player move from the current room to a neighboring room. Redirected Walking appeared to be feasible at first but did not perform well on the limited 5 x 5 meters movement area. Instead, a second type of Passive Walking—besides the escalators—was required to let the player switch to a neighboring room on the same floor: Though flat passenger conveyors are not typical for shopping malls and are therefore not an ideal solution for our prototype, most people know them from airports—and they are both intuitive and simple to use.

The mall's offices (see Fig. 3) can be reached by using the elevator available on the ground floor. Once the elevator and the player have arrived, an infinite level system allows for the exploration of dynamically created variations of offices and adjoining corridors procedurally generated by a level generator.

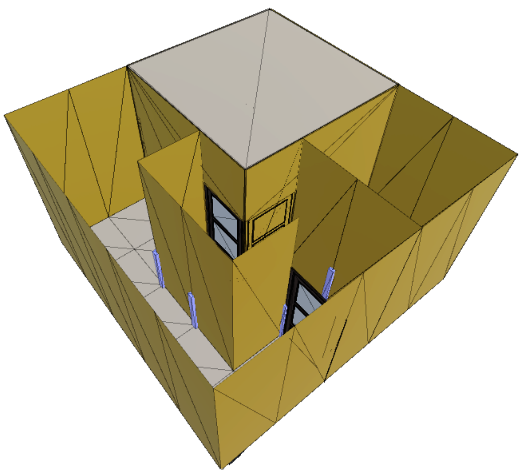

Figure 3: Example of a procedurally generated part of the fourth floor with offices

Concerning interaction with and in the virtual environment, our game prototype offers a natural, intuitive method of inputting with the hands instead of working with cumbersome hand controllers and their inaccurate mappings. The implementation of Oculus Quest hand tracking allowed for an immersive representation of the player's hands plus haptic feedback when she touches real objects. To achieve this, we mounted physical buttons on touchable pillars on floor plates within the movement area (see Fig. 4 & 5). Pressing a button can therefore be haptically perceived by the player. In the virtual environment, pressing a button triggers the Passive Walking methods in our game, i.e. passenger conveyers, escalators, and elevators.

The pillars and buttons are thus locally anchored in the level design. Every room in our shopping mall must therefore either contain the pillar and the button or avoid them by hiding them from the player or moving the player around them. To synchronize the virtual world with the position of the buttons on the physical floor plates, the alignment of the virtual world is overlaid with the alignment of the physical world when the game is started.

Figure 4: The movement area with eight pillars on floor plates

Figure 5: Haptic interaction with physical buttons

4 Design Analysis & Discussion

Only two of the three methods introduced in section 2 could be implemented in our prototype: Infinite Walking via level generation for the offices and corridors, and Active/Passive Walking for the publicly accessible areas of our virtual shopping mall. Redirected Walking was initially considered and tested, but could not be implemented: As calculated in [2], Redirected Walking would have required approximately 40 x 40 m to guide a user on a circular arc in the physical world, while walking straight in the virtual environment.

In addition to procedurally enabled Infinite Walking and Active/Passive Walking, visual effects and tricks were employed to create the impression of a realistic environment and realistic movement. To begin with, the shopping mall, its shops and the office rooms are furnished in a way that lets the player immediately recognize that she is inside a shopping mall. Also, the mall has been designed to look more spacious than it actually is. For example, the player can look into closed shops with fully visible shop areas, sometimes through transparent windows (see Fig. 2). She can also see non-accessible areas that are visible only while riding the escalators (see Fig. 6). Similarly, the procedural generator also creates areas that are visible, but inaccessible.

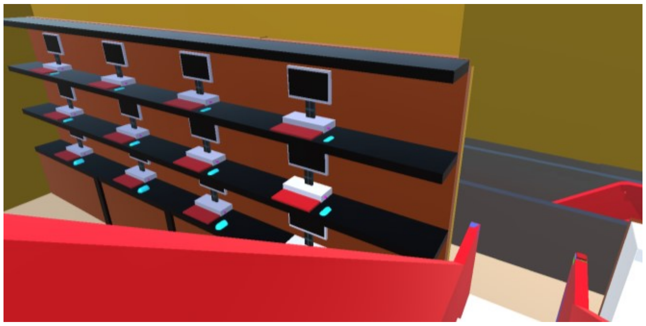

Figure 6: Looking into a computer store while riding the escalator from the third floor down to the second floor. The escalator to the entrance hall is also visible.

To prevent the player from walking in one direction for too long, the level generator creates a complex, nested architecture, forcing the player to turn on her heels, i.e., by 90 degrees, quite often. This also forces the player to slow down instead of moving quickly through the procedurally generated areas. However, small errors can accumulate over time, for example, when the user turns by slightly more or less than 90 degrees, or the level generator generates less than optimal corridors. Our level generator therefore has a built-in fallback feature that guides the player back to the starting room on the fourth floor, where she must take the elevator back to the customer area of the shopping mall.

To give the player even more freedom, the game was developed for the Oculus Quest which is not wired, but works wirelessly, so that the player has more freedom of movement and hand tracking. Hand tracking is especially important when using the haptic elements in our game, i.e., the eight physical buttons mounted on pillars. They allow the player to actually press buttons both in the simulation and in the real space, and while being passively moved on a conveyor or escalator, she can place her hands or arms onto the buttons on her right and left side, as if she was placing them on the handrails of real escalators or the armrests in an elevator. Inside the game, the buttons give the player more control over the environment: Using these buttons, she can activate conveyors, escalators, and elevators. This allows her to switch manually between Active and Passive Walking.

It is the neat combination of the above-mentioned techniques and tricks that creates an impression of realistic movement and realistic interaction, and thereby increases the feeling of immersion. Unfortunately, due to the COVID-19 pandemic, only our team could test the prototype. User-testing to assess the actual feeling of immersion could not be conducted.

Due to the limited physical space of only 5 x 5 meters, several problems persist. In particular, the gamer can still move in a way that the game could not cope with. For example, the player might try to move through walls or accidently step aside while riding an escalator or elevator. She might even try to walk through a transparent window into the shop area of a closed shop. To signal the player that she moved outside the accessible area, the prototype turned the display black to stop the player from moving further, subsequently maybe even hitting a pillar or stumbling outside of the movement area.

Effectively, most accessible areas in our game are still very small. Offices on the fourth floor are limited to 2 x 2 or 3 x 3 meters, and escalators, elevators, and corridors are rather narrow. In there, the player should not stretch out her arms, because they might disappear in a wall. Without Redirected Walking, the limitation of the physical space, i.e., the 5 x 5 meter movement area, can only be partially overcome.

5 Conclusion

Our prototype proves that a combination of techniques such as Infinite Walking, Active/Passive Walking, visual effects, haptic elements, narrow corridors, visible but inaccessible areas, and so on, can be used to design a three-dimensional virtual environment —at least, a multi-floor building—with hundreds of square meters on a plain sensor area of only 5 x 5 meters. We have also shown that procedural generation can account for potential obstacles in the physical space, such as the pillars with buttons depicted in Fig. 4 & 5, and integrate them into the procedurally generated levels as haptic elements that can be used in parallel in the real and the virtual world.

Similar combinations of techniques, tricks, and methods of movement could potentially be applied to many other virtual scenarios, such as showrooms or virtual exhibitions. We assume that the improved realism, freedom of walking, haptic experience and control over the environment may let players or users, respectively, immerse deeper into their virtual environment, but this must still be proven by adequate user tests.

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