# Design and Development of a VR Wheelchair game with Redirect Movement

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***Abstract.*** *In this paper, we explore the development and design of an accessible virtual reality (VR) game aimed at fostering empathy for wheelchair users, and to simulate their challenges. The game design integrates a novel redirect movement system, enabling realistic locomotion within a virtual space without extensive physical movement. This system, developed using only an all-in-one head-mounted display (HMD), adjusts the user's position seamlessly to maintain immersion and comfort within three scenarios. This work contributes to the broader field of VR accessibility and serves as a model for developing inclusive VR applications that cater to diverse user needs. Future directions include developing and evaluating additional games.*
***Keywords*** *Redirect Walking, Redirect Movement, Virtual Reality, Wheelchair, Able Games*

## 1. Introduction

The metaverse exemplifies the increasing integration of VR into daily life, with more people gaining access despite the associated costs. In the US, in 2020, one in every five people has used VR, and 30% of US citizens use it monthly [ARI 2020]. The development of VR games aims to go a step further in VR accessibility through the design and improvement of new ways to interact in the virtual environment while paying attention to the user's perception and well-being.

In summary, Virtual Reality (VR) has been identified as one of the most promising resources for developing empathy toward stigmatized groups, as it allows individuals to experience a situation close to reality from another person's perspective[Bertrand et al. 2018].

In this paper, we propose and describe a guideline for designing and developing a VR wheelchair game whose main goal is to make users experience firsthand the main difficulties faced by wheelchair users. We followed the user-centered design process to identify and ideate the game context and interactions adequately to create an experience of empathy for the users.

## 2. Redirect Movement

This chapter will examine all redirect movement types, discuss novel techniques researchers develop, and rethink preconceived knowledge that may limit the creation of new ideas.

### 2.1. Why Redirect Movement?

Razzaque and others [Razzaque et al. 2001] developed a locomotion system to create an immersive experience by combining two essential concepts to consider while developing VR experiences: Infinite Worlds and Real Walking.

Over the years, researchers have been bending their ideas from creating new techniques and changing how to locomote in reality to repurposing existing methods and the environment itself [Suma et al. 2009]. The concept of ”redirect walking”is no longer capable of containing all the existing advancements in this area of research. However, it also wrongly names redirect jumps, as in Hayashi and Yamamoto's works [Hayashi et al. 2019, Yamamoto et al. 2018], stretching and crouching, for example, in Matsumoto's works [Matsumoto et al. 2020], and even wheelchair drives, such as Bruder and Sassi's works [Bruder et al. 2012, Sassi et al. 2023].

Li [Li et al. 2022] reviewed several new redirect walking techniques. After an extensive explanation of different methods and a proposal for redirect walking techniques, they recognized the existence of other forms of locomotion and separated them from redirect walking. Therefore, continuing this thought in this paper, we will use the term Redirect Movement to encapsulate every redirect locomotion in VR.

### 2.2. Types of Redirect Movement

There are several methods and techniques of Redirect Movement, but all start with one of three basic types of redirection: translation, rotation, or curvature. Redirected translation allows users to traverse a virtual environment at scales different from real-world movements. By monitoring the user's movements, a VR application can adjust their motion using a specific gain factor, enabling the user to cover more or less distance.[Steinicke et al. 2010, Steinicke et al. 2008, Nguyen 2021, Nilsson et al. 2018].

Redirected rotation allows users to rotate different amounts in VR compared to the real world while remaining stationary. While developers can apply this technique in various directions, it is the most common around the yaw axis (vertical). [Steinicke et al. 2010, Steinicke et al. 2008, Nguyen 2021, Nilsson et al. 2018].

Circular redirection works similarly to rotation redirection but applies rotation around the yaw axis while the user moves forward. This technique allows the user to walk on a straight virtual path while moving on a circular path in the real world.

## 3. Redirect Movement Implementation

$$GPos = g_t * d - d \tag{1}$$

We developed a redirect movement algorithm that tracks and adjusts the user's position using only an all-in-one HMD, adjusting the guardian's position instead of changing the user's position within the game. By attaching the user's position to the

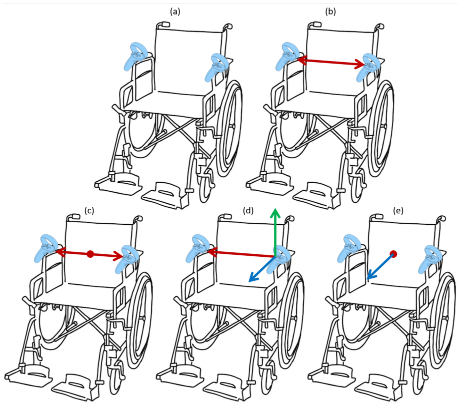


**Figura 1. Diagram of how the program calculates the real wheelchair position and rotation from the VR controllers.[Sassi 2023]**

guardian, we could update the distance traveled in each frame by relocating the guardian. Equation 1 outlines how we calculated the guardian's position $GPos$ in every frame based on the user's distance $d$ traveled and the redirect translation gain $g_t$.

Fig 1 shows all the steps to track the player's position. First, it illustrates where the controller was attached to the wheelchair. Next, the system calculates the distance between the controllers based on their positions, with the red arrows representing the distance vector. Then, the midpoint from the distance vector is calculated. By performing a cross-product with the distance vector and an up vector, the direction the wheelchair is facing can be determined. Finally, using the mid position and the vector indicating the wheelchair's facing direction, the virtual wheelchair can be positioned in the same place, facing the same direction.

## 4. Experiment

To validate our proposed framework, we developed a game that uses the concept of Wheelchair redirect movement in its gameplay.

### 4.1. Designing the Concept

The game design followed a User-centered design (UCD) approach in which designers focus on the users and their needs in each phase of the design process[Norman e Draper 1986]. Our work team conceived various ideas through a brainstorming session, considering that the player should play from a wheelchair perspective, with user movement being redirected. For this paper, we present "SuperWheels", a recognizable 3D platform game where the goal of each level is for the player to move between points in the environment, surpassing uneven terrain, suspended platforms, and unusual traps.

Our development is grounded in ability-based design (ABD), a method for developing applications based on what users can do and how systems and environments should adapt to them[Wobbrock et al. 2018] and by Mott [Mott et al. 2019] who define five areas that the VR community should consider so virtual experiences are accessible by design.

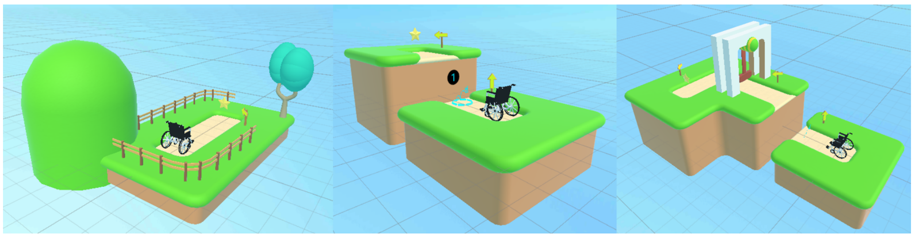

**Figura 2. Levels 1, 2 and 3 from SuperWheels.**

### 4.2. Player's Setup

The user, equipped with the Oculus Quest 2, must play the game without engaging the controls. The controls were attached to the wheelchair's armrest to precisely track the player's position and direction during the experiment. The player, an integral part of the game environment, interacted with it through movement or gaze whenever necessary.

### 4.3. Developing SuperWheels

We developed the game using free online assets to resemble known games from the platform genre. With a slow progression, each level intends to teach a different mechanic. Three variables change from a 3D mechanic platform game: The user is in VR, in a real wheelchair, and being redirected. Following we will explain how we crafted each part per level. Fig 2 summarizes all levels.

On level one, the player learns to move and reach the goal using redirect translation. Although the goal is to reach a star, moving forward in VR would require significant real space. To address this, we reset the level whenever the player achieves their goal or dies, ensuring they always start from the same real position.

On level two, the player learns to jump. Jumps in VR can cause cybersickness due to unnatural movement, acceleration, and changes in the field of view[Porcino et al. 2022]. To mitigate this, we implemented a jump timer and a coned view to reduce velocity and acceleration, making the movement smoother and less abrupt.

On level three, the player encounters a turning hammer that can hit them, leading to death either by the hammer or falling off the terrain. Upon dying, the player receives only auditory feedback and a black screen to avoid discomfort and cybersickness from animations or movement feedback.

## 5. Conclusion and Future Works

In this work, we propose how to design inclusive games for wheelchairs purposes through XR platforms. To make movements more practical, we include and develop redirect movement strategies, allowing extended realistic movements and interactions. We propose a design thinking-based workflow for designing such kinds of games and validate the proposal by implementing one game, named SuperWheels. Based on our practical implementation, we propose several practical interface and gameplay solutions, opening an important and relevant area for inclusivity and games. For future works, we intend to develop more games, trying to approach different gameplay styles and different purposes of wheelchair inclusivity, exploring the proposed redirect movement in various manners. Also, we pretend to increase our evaluation approaches, including usability and cybersickness tests[Porcino et al. 2022].

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