A Cost-Effective Virtual Environment for Simulating and Training Powered Wheelchairs Manoeuvres

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Abstract. Control of a powered wheelchair is often not intuitive, making training of new users a challenging and sometimes hazardous task. Collisions, due to a lack of experience can result in injury for the user and other individuals. By conducting training activities in virtual reality (VR), we can potentially improve driving skills whilst avoiding the risks inherent to the real world. However, until recently VR technology has been expensive and limited the commercial feasibility of a general training solution. We describe Wheelchair-Rift, a cost effective prototype simulator that makes use of the Oculus Rift head mounted display and the Leap Motion hand tracking device. It has been assessed for face validity by a panel of experts from a local Posture and Mobility Service. Initial results augur well for our cost-effective training solution.

Keywords. Powered Wheelchair, Oculus Rift, Leap Motion, Virtual Reality

1. Introduction

Learning how to control a powered wheelchair (such as the model shown in Figure 1.) can be a daunting task, particularly for individuals with severe, or multiple motor limitations [4,9]. Although modern buildings increasingly cater for disability access [11], challenges that cannot be solved architecturally still exist such as improving a persons spatial awareness, familiarisation with the wheelchair, and reaction times. Currently, there are very few tools available within a typical posture and mobility clinic to assist this process [2]. We hypothesise that a serious game environment that utilises emerging and affordable computer interface technologies can provide a safe environment in which a new user of a powered wheelchair can learn how to operate and navigate it in a variety of different scenarios. Towards exploring this hypothesis, we present a virtual environment for training powered-wheelchair users. The objectives of the project are:

i) To provide an interactive, immersive virtual environment that enables training in powered-wheelchair navigation by realistically simulating wheelchair movement within graphical representations of a built environment.

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Figure 1. The Spectra XTR wheelchair (used at a local Posture and Mobility Service in North Wales) is the default model for our simulated powered chair. We can also change parameters in the software to support other chairs.

ii) To provide a realistic optical-flow simulation of wheelchair motion to induce the feeling of the physical effort required to propel a wheelchair over changes in floor surface and slope.
iii) To simulate natural interaction with obstacles and room furniture such as doors or elevator controls.

2. Background

The first attempts to use virtual reality (VR) to help train users of powered wheelchairs took place in the late 1990s, but were hampered by the limitations in available technology. Inman *et al.* [7] focussed on developing entertaining environments that would motivate children. They demonstrated that certain aspects of the childrens driving skills did improve through training in VR. Interestingly, they noted that many of the children chose to look at a large monitor rather than using a head-mounted display (HMD). However, the resolution of HMDs at the time was far inferior to that of monitors, and they would have been cumbersome to wear.

A non-immersive VR Training System for disabled children was also developed by Desbonnet *et al.* [3], who provided good face validity by using the actual wheelchair controller fitted to the chair. Yet the visual realism achieved and the modelled wheelchair behaviour were not sufficient. These were highlighted as important areas to address in future work. Harrison *et al.* [5] carried out a comprehensive study to explore the use of VR in the assessment and training of powered wheelchair users. However, the experience was again non-immersive, using a computer monitor to display the virtual environment. Experienced users were given an opportunity to explore a real-life environment before using the VR system. Practice using the interface device (a wheelchair joystick in this scenario) also took place beforehand. The findings were that generally users were quicker in real life than in VR, the slowest in VR being tasks to drive the wheelchair into and out of an enclosed space; complete a 180 degree turn around a stationary object; and completing a slalom. The number of collisions and individual manoeuvres required in VR were also considerably more than in reality and were attributed to slight differences to the real life chair. The authors conclude that whilst showing potential, the virtual environments need to be less challenging if they are to represent a motivating and effective means of improving performance.

More recent studies by Linden *et al.* [8] provide evidence of the effectiveness and value of virtual wheelchair training simulators. These studies demonstrated that VR interventions can be effective in training children in the control of a powered wheelchair.

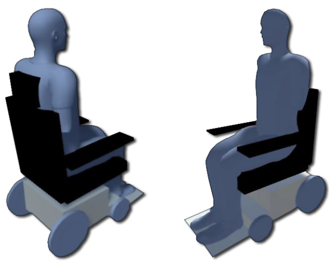


Figure 2. The simulated chair used in Wheelchair-Rift. A model of a user is paired with the chair to ensure that when the user looks around they see their body as they would do in a real wheelchair. This helps maintain the users immersion and sense of presence. Note the lack of forearms, which are rendered during simulation via the Leap Motion.

The Oregon Research Institute Applied Computer Simulation Labs have also produced a wheelchair simulator called Wheelchair Net [2] designed to help orthopaedic patients learn to operate a powered wheelchair by practising driving manoeuvres in three different virtual environments. The computer monitor view is first person with the ability to pan up and down to the point where the wheelchair users legs are visible. The simulation is controlled mainly with arrow keys on the keyboard. There are options for adjusting the wheelchair configuration before the simulation begins.The software also supports multiple users, which is a useful feature. However, results of studies using this software have not been reported.

Virtual environments can also be used to prototype new parts for a wheelchair. Cooper *et al.* [1] compared a new isometric joystick for a powered wheelchair with the traditional position sensing joystick in this manner. They found that performance in the virtual environment was representative of driving ability on the real environment.

Considering that in 2005 there was an estimated 1.2 million wheelchair users in the UK alone [10] (roughly 2% of the population) there is clearly a large audience for a dedicated training tool. However, at the time of writing this paper, we are not aware of a computer-based training solution that has gained large scale clinical usage, which justifies ongoing research and development of such simulators. With new, high fidelity interfaces for virtual reality such as the Oculus Rift head mounted display and Leap Motion hand tracking device becoming readily available at an affordable cost, it is timely to investigate a more intuitive, affordable, immersive virtual environment for training users of powered wheelchairs.

3. Method

Wheelchair-Rift has been developed using the Unity 3D game development platform (Unity Technologies, San Francisco, CA). It will operate on any standard PC or Mac platform.

3.1. Wheelchair Model

Most wheelchairs use the same control strategy as that used in the first powered wheelchair, the Klein Drive Chair, introduced in the 1950s. This relies on the indepen-

[2] Wheelchair Net can be downloaded from `http://simlabs.ori.org/downloads/cat_view/52-wheelchair-mobility-training-software.html` but is no longer being developed.

Figure 3. The Leap Motion is attached to the front of the Oculus Rift DK2 using the VR Developer Mount. The wheelchair control joystick is represented by one of the joysticks on an XBox 360 Gamepad.

dent control of the two powered wheels, usually in the rear, and the free motion of pivoting front caster wheels. Direction changes are made by individually varying the speeds of the rear wheels. The interface between the user and the wheelchair itself is often the most critical component. Hand-operated joysticks with proportional control are now the *de facto* interface for most wheelchair users. They do not rely on the users strength in the upper limbs to operate wheels nor require a permanent assistant pushing from behind. Our simulated wheelchair (Figure 2.) attempts to recreate this feature as faithfully as possible.

A 3D model provides the basic geometry of a specific type of wheelchair and, importantly, the position and size of the wheels. Wheel colliders and a rigid body component are subsequently added to the 3D model. The wheel collider is a specific type of physics collider that is attached to a virtual axle allowing it to rotate, and when torque is applied it can be driven. By adjusting the size, position and friction curves of the wheel colliders various wheelchair configurations can be created. For the Spectra XTR (a rear-wheel drive chair, with skid steer and casters on the front) the friction of the rear wheels was set to normal levels, whereas the front wheels had their forward and lateral friction set low. Lowering the friction of a wheel collider is the typical way to simulate a caster in a games engine, as it allows free movement in two dimensions. When power is applied asymmetrically to the rear wheels, it allows the chair to turn, simulating the same control procedure as the real-world analogue. The joystick control on an XBox 360 Gamepad (Microsoft, Redmond, WA) is used to provide a suitable wheelchair-like joystick interface for driving the virtual wheelchair - see Figure 3.

3.2. Viewing and Tracking within Wheelchair-Rift

Wheelchair-Rift uses the Oculus Rift DK2 HMD (Oculus VR, Irvine, CA), which provides a 3D stereoscopic view of a computer generated environment (Figure 3.). The Rift is supported within Unity using a manufacturer supplied plugin that automatically sets up a stereo camera configuration. A particular requirement supported by the Rift is that it allows the user to look around by turning their head, without turning the chair, resembling how a real wheelchair user would inspect their surroundings. The DK2's head tracking also allow allows the player to lean forwards and back, providing input for positional as well as rotational movement.

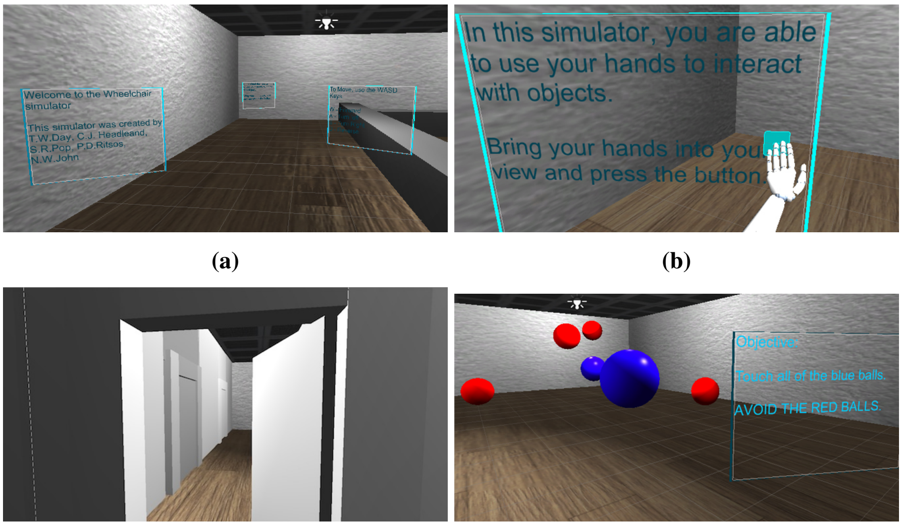
Hand gestures and movements are tracked by means of a Leap Motion tracking device (Leap Motion Inc., San Francisco, CA), mounted on the Rift (Figure 3.). The Leap Motion uses two infra-red LED's and two monochromatic infra-red cameras. It estimates a skeletal model of a hand by comparing the frames generated by the two cameras. As the users hands move in front of the tracker, the detected skeletal model recreates the users hand movements in the virtual world allowing the user to interact naturally with in-world objects. The Leap Motion is integrated into the Unity3D game engine through use of a plugin provided by the manufacturer.

3.3. Training Environment

Wheelchair-Rift is built with the principle intention of assisting in the training of new wheelchair users. To achieve this goal we employ gamification, abstracting the skills required and used during powered-wheelchair navigation. In addition, incremental training strategies allow the user to challenge themselves in alignment with the ongoing development of their ability.

The user is tasked with moving through a virtual multi-story building, as if they are driving a physical wheelchair in a physical environment. A virtual elevator is used to access different floors, on which there are specific training scenarios. Following completion of the scenario, the user returns to the elevator to select a new floor. The higher in the building they go, the more difficult the training task. In the current version of the simulator, four floors of the training building have been created. These environments teach the user how to operate the wheelchair controls and provide specific training scenarios that enable them to experience access issues that are typically encountered. The current scenarios are:

1. **Lobby**: The first room in the building is the lobby. The purpose of this room is to allow the user to acquaint themselves with the wheelchair, and using the Leap Motion to naturally interact with the environment (see Figure 4a and b). Text based information is provided on boards along a simple path (depicted in Figure 4a). Some of the information boards contain simple tasks, designed to facilitate the users familiarization with the chairs controls, and the hand gesture interaction (for example see Figure 4b).
2. **Maze**: The second floor of the training environment is a simple maze, requiring the user to make several turns and manoeuvre through doorways. The user must also reach out and press a series of buttons to open doors (see Figure 4c).
3. **Floating Balls**: On the third floor the user is presented with randomly positioned spheres of blue and red. The user has to navigate the environment and touch the blue balls with their hands whilst avoiding collisions with the red balls (see Figure 4d). The user is challenged to complete the room in the shortest possible time. This room is an increase in difficulty from previous scenarios as it requires the user to make precise, turns and manoeuvres.



(a) **(b)** **(c)** **(d)**

Figure 4. A selection of training environments from the current version of Wheelchair-Rift. Subfigures (a) and (b) depict the first level, where the user is provided with basic text instruction on how to operate the chair and interact with the environment. (c) shows the second level, a maze of doorways to allow the user to practice rudimentary navigation. (d) is a more complex environment where the user must move around the scene, touching the blue balls while avoiding the red ones.

4. **Moving Obstacles**: On the fourth floor the user must move through a room activating buttons in a sequence. While they undertake the task the user must avoid collisions with various human-size obstacles that move randomly around the room. This simulates a challenge similar to that faced by wheelchair users in crowded environments.

4. Results

The current version of Wheelchair-Rift was evaluated by a panel of three experts from a local Posture and Mobility Service. The purpose of this preliminary evaluation was to provide initial face validation before a future construct validation study. In particular, we needed to assess the fidelity of the virtual wheelchair's functionality (e.g. rotation speed, braking modulation etc.) and to inform future training scenarios. Each member of the expert panel used the simulator for 15-20 minutes and went through the four training environments. At the end of each training session the panel member provided qualitative feedback, which was collated. The evaluation was carried out using a standard laptop running Windows 10 with a 2.6ghz I5 processor, a NVIDIA GeForce 740m Graphics Processing Unit, connected with an Oculus Rift and Leap Motion.

Overall, the simulation was characterized as accurate in its operation, with the feeling of immersion, interaction and environment quality as strong points. A series of parameters were identified for adjustment, namely the turning speed and braking speed. The panel also emphasised that the simulator requires a series of adjustable parameters that can be tuned to suit individual users. Although clients are generally issued with the same wheelchair model, these may be set-up differently to suit their disability, e.g., lowering the top speed.

Regarding the validity of the training scenarios, the response was positive, highlighting the suitability of the challenges incorporated (e.g. entering an elevator and rotating to access the buttons). Moreover, various other navigation skills were identified that would benefit from inclusion in the simulator. The first was manoeuvring over and around access ramps; the second was driving through doors into tight corridors; the third was driving down tight paths with curbs.

Lastly, the panel discussed the currently-enforced training procedures for clients and the various assessments that a future wheelchair user may be required to complete, such as spatial perception and vision tests.

5. Discussion

We have described the development and testing of the alpha version of our wheelchair simulator [6] which has addressed objectives (i), (ii) and (iii) of our ongoing project. We have provided a practical and cost effective solution that has received positive feedback from our clinical collaborators. Future work will seek to address the feedback provided by the expert panel, specifically the new training environments, and customisation options for the wheelchair model (in particular the different handling of mid-wheel and rear-wheel drives). After completing these additions, the Beta version of the simulator will be subjected to a construct validation study. This will be in collaboration with several different posture and mobility service units covering different regions of the UK, and is currently being planned. It will involve documenting the screening and assessment processes used in the different units, including methods for measuring visual acuity, inattention of users, and reaction times. A controlled study will then be conducted to compare the driving skills performance of users who have had access to Wheelchair-Rift with those who just use the standard training currently offered in the unit. The latter is often minimal.

Haptic feedback has been omitted from the current prototype, however, we are currently experimenting with with various cost-effective haptic devices (including the Novint Falcon) to give extra feedback on the terrain being traversed. We are also planning an augmented reality wheelchair driving system where a real powered wheelchair will be used but the obstacles seen in the room will be computer generated.

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