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Project (Technical Computing)

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Author:	**Nico Caruana**
Student ID:	**27022205**
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Supervisor:	**Dr Peter O'Neill**
Second Marker:	**Mick Marriott**
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Confidentiality Required?

YES☐ / NO☒

I give permission to make my project report, video and deliverable accessible to staff and students on the Project (Technical Computing) module at Sheffield Hallam University.

YES☒ / NO☐

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Abstract

For many people with mobility issues an electric wheelchair is a necessity. However, learning to drive one can be a daunting prospect, with mistakes proving potentially painful and/or costly.

This report investigates the problems associated with driving a powered wheelchair and the skills needed to operate one successfully. The project discusses the development of an application simulating a wheelchair, with an aim of allowing a user to practice and improve their driving skills without endangering themselves, any third parties (such as carers) in the vicinity, or their environment.

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1 Introduction

1.1 Project Overview

For many people with mobility issues an electric wheelchair is a necessity. However, learning to drive one can be a daunting prospect. The learning curve can be quite steep depending on the user's confidence in using technology; mistakes and accidents can be potentially painful and/or costly.

The Assistive Technology Team at Barnsley Hospital have requested that an application be developed to provide the user with a safe way to practice their wheelchair driving skills. The application would ideally provide a close to real-life experience for the user and be able to be controlled using a real wheelchair input device, such as a joystick, or switch/es. However, they are willing to compromise on realism provided the underlying skills are being taught.

This project aims to explore whether an application can be developed to emulate a wheelchair allowing a user to practice and improve their skills without endangering themselves, any third parties (such as carers) in the vicinity, or their environment and determine its value as a tool in the learning process.

1.2 Project Aims and Objectives

- Investigate real-world wheelchair operation, existing wheelchair training solutions and other applications that offer a simulation experience.
- Investigate the possibility of implementing an actual wheelchair joystick as the application controller.
- Implement the research findings into a realistic driving experience and include gamification.
- Improve the application experience using feedback from Assistive Technology Professionals (ATP) and Service User Representatives (SUR).

2 Research

2.1 Identifying the problem

Powered wheelchairs are an expensive piece of technology with prices ranging into the thousands of pounds (Sunrise Medical, 2021). Repair costs are often exacerbated by call-out fees and labour costs of a professional wheelchair technician. It has also been evidenced that there can also be considerable adverse consequences for the user if the chair is rendered inoperable and a suitable replacement is not available during the time needed to action the repair (Henderson, Boninger, Dicianno, & Worobey, 2020).

2.1.1 How big is the problem?

A study of wheelchair related injuries treated in emergency departments in the US shows that incidents rose from 50,000 in 1991 to over 100,000 in 2003 (Xiang, Chany, & Smith, 2006). Tips and falls were responsible for between 65-80%. It should also be noted that 17% of admissions required hospitalisation.

In a Taiwanese study of experienced wheelchair users between 2006 and 2008, it was found that 54% of the participants had been involved in one or more accidents in the preceding 3-year period (Wan-Yin Chen, Yuh Jang, Jung-Der Wang, Wen-Ni Huang, Chan-Chia Chang, Hui-Fen Mao and Yen-Ho Wang, 2011). Of these accidents, 87.8% were classified as a tip or fall which could have a significant effect on the health and wellbeing of the user both physically and mentally.

A more recent Swedish study looking at data from 2007 to 2016 found that there was a total of 743 accidents reported to the Swedish Traffic Accident Data Acquisition database. This was representative of a 3-fold increase over the period. Of the incidents, 316 were collisions with other vehicles and 427 involved only the powered mobility device. The solo accidents resulted in an 87% rate of the driver impacting the ground. A large proportion of the resultant injuries were to the head and the hips (Carlsson & Lundälv, 2019).

2.1.2 What poses the greatest threat?

From the data obtained when looking at the scale of the problem, the largest threat to a wheelchair user in terms of frequency and severity of the outcome is being ejected from the chair itself. To understand the cause of this, a closer inspection was needed.

Delving deeper into the Swedish study, the largest portion 34% of solo vehicle accidents occurred when the user was attempting to traverse a difference in height, for example dismounting a kerb. This is followed by 11% being down to the impact with a stationary object, 10% the result of a poor-quality driving surface and 9% from an unexpected change in driving surface (Carlsson & Lundälv, 2019).

A study comparing actual wheelchair performance to users' perceived skill levels produced more detailed information about specific problem manoeuvres (Rushton, Kirby, Routhier, & Smith, 2016). The most problematic were "Getting from ground to wheelchair" (10% success rate), "Disengaging and Engaging motors" (30.9%), "Operating battery charger" (44.1%), "Transferring out of the wheelchair and back" (44.4%), "Getting over 15cm pothole" (52.8%), "Ascending a 5cm level change" (54.9%), "Picking up an object from the floor" (56.3%), "Manoeuvre sideways" (62.8%), "Getting through a hinged door" (71.8%). The users' perception of their skill level and chance of success was extremely accurate for the most part, however, there were a couple of interesting outliers. In the cases of "Ascending a 5cm level change", "Getting over 15cm pothole" and "Manoeuvre sideways", the users perceived their skills to be far higher than their actual success rate. Considering these areas have previously been shown to be significant causes of accident, it may indicate that complacency could be a considerable factor. Also, worth noting is that the users significantly overperformed their estimations on the "Getting through a hinged door" task.

2.1.3 Where is the problem encountered?

With some understanding of the likely problem areas, the next step was to determine the frequency and context of them being encountered during daily life.

A study to create an accessible route mapping application for wheelchair users in Northampton, England shows that there are several real-world barriers in even the smallest of journeys (Beale, Field, Briggs, Picton, & Matthews, 2006). Steps, high kerbs, both supervised and unsupervised road crossings, raised manhole covers and fixed street furniture all have potential to force the use of a risky manoeuvre. Attention was drawn to the type of surface driven on, as well as its state of repair and in many instances, there was no choice but to navigate across poor-quality surfaces. Also noted but not measured was the impact of pedestrian movement and congestion on accessibility.

As part of the BBC's Disability Stories series, an interview was conducted with a wheelchair user, Edward Maxfield documenting some of his daily challenges navigating the streets of Edinburgh, UK. In the video there was a gross amount of uneven floor surfaces, with one area proving to be the cause of an accident resulting in damage to a caster wheel and causing personal injury. Most of the pavements were narrow and adorned with both static street furniture and litter, limiting manoeuvrability, and increasing the risk of an unexpected change in driving surface. There were very few dropped kerbs meaning that ascending and descending 5-10cm level changes would be forced to occur multiple times per day. Also evidenced was the failure of an intended accessibility aid, in the form of a temporary ramp not being placed correctly, which proved to create an impassable barrier and forced a complete re-routing (Maxfield, 2020).

2.2 Existing solutions

2.2.1 Training Applications

A study aiming to get an overview of the current use of wheelchair simulation, with a focus on Virtual Reality (VR) environments, evidenced that there has been a recent resurgence in the number of research papers produced (Arlati, Colombo, Ferrigno, Sacchetti, & Sacco, 2020). This was speculated to be most likely being due to the improvements in technology, and reduced costs associated with obtaining and working with it. From the study, data was examined to try to pinpoint the areas which seem to produce the best results. For example, all the studies, regardless of how the environment was visually presented, had systems that were controlled by use of a joystick. It was also noted that a large proportion focused on the general driving aspects of using a wheelchair, with only three examples choosing to focus specifically on reproducing daily activities.

Virtual Reality

WheelchairNet

A study attempting to investigate their efficacy of supplementary wheelchair training tools using VR technology in the improvement of real-world wheelchair driving skills in children (Inman, Loge, Cram, & Peterson, 2011). In the study, the training application provided three different environments and aimed to promote different styles of learning. Independent learning driven by intrinsic motivation of play and discovery was cultivated in an open world layout with no time limits or goals. Structured, skill-based learning using was encouraged by using predetermined skill-based test scenarios which were timed. Data showed initial application usage was spent mainly in the independent learning, but as the user became more skilled, they spent more time attempting the skill-based challenges. Usage of the application showed an improvement in driving skills that translated across to real world application.

Screen Based

miWe

The McGill immersive wheelchair simulator (miWe) is frequently featured in studies and its progress over the years has been examined.

In an early study, a comparison was made between the users driving performance when using a real wheelchair and their use of the software with an aim to determine whether the software would be perceived similarly to a real-world situation and therefore have potential as a training aid (Archambault, Tremblay, Cachecho, Routhier,

& Boissy, 2012). Observations were indicative of showing that users would deliver the same number and type of input gestures to both systems, signifying that there could indeed be potential in the system. However, many of the actions in the virtual world were hampered by lack of depth perception and quality of simulation at the time.

In a later study into the comparison of the use of miWe to the use of an unnamed racing game, within in a home environment, aimed at evaluating the improvement of wheelchair driving skills gained, it was determined that regardless of activity the users were extremely keen to engage with the platform (Archambault, Gagnon, Routhier, & Miller, 2016). All participants spent far more than the minimum required time with the software. The miWe simulator provided environments situationally relevant to wheelchair users, such as bathrooms, supermarkets, and street crossing. Findings from the research indicated that all the users experienced increased wheelchair-driving skills, with the miWe users showing slightly more improvement. This likely suggests that the training exercises were more focused on developing the specific action sequences required in the Wheelchair Skills Test (WST). They concluded that promoting the practice of specific activities complementing clinical basic skills training may be the ideal solution.

A further study using miWe investigated the effect of augmented feedback during the wheelchair simulation (Bigras, Kairy, & Archambault, 2019). A user was provided with terminal feedback, a display of statistics related to their driving, a top-down view of their trajectory with collision/near miss points highlighted and the ability to view each collision to see which part of the wheelchair was involved. Results showed that the feedback provided did slightly improve user performance, but only in the short term (20 minutes after first test). When re-tested after two days, the performance level had dropped. This suggests that terminal feedback would be a useful addition but would need frequent consistent application before any lasting effects could be observed.

Unnamed study into 4C/ID Learning Model

A study into the use of screen-based wheelchair simulator software with school aged children evidenced small improvements in real-world driving after use (Linden, Whyatt, Craig, & Kerr, 2013). The simulator offered short, timed courses with a variety of turns and ramps with static obstacles to avoid. The most notable observation was that the children were reluctant to engage with the environments when they presented more difficult tasks which required finer motor controls. Also of note was that female learners showed less of an improvement than their male counterparts.

ViEW3D

A study using the ViEW3D wheelchair simulator provided a representation of a specific outdoor situation, with a view to improving and assessing wheelchair skills of users affected by Cerebral Palsy (Morère et al., 2018). The users in this situation were required to transfer between campus buildings safely, with more obstacles being added to increase the difficulty. Assessment was based upon user's ability to follow a designated path, the jerk values between inputs, and their overall manipulation of the controller amplitude. Provided some evidence of user skill improvements, but notably mentioned that user's driving behaviour did not improve to the same level.

2.2.2 Games

Although car driving games are commonplace in mainstream gaming, it seems wheelchair-based games are much rarer. A selection of currently available products is reviewed in this section.

Wheelchair Simulator / Wheelchair Simulator VR

Available on the Steam platform, developed and published by independent company ViRa Games, Wheelchair Simulator (ViRa Games, 2018a) and Wheelchair Simulator VR (ViRa Games, 2018b) focus on creating a whimsical version of wheelchair navigation. Low poly environments and models with deliberately rigid animations enhance the games comedic appeal. The game features manually operated wheelchairs only, and in the VR version, encourages the user to use the hand controllers to push the wheels like a real chair. The levels consist of various static and mobile obstacles, and collisions with them result in the player model being ejected from the chair with comedic exaggeration whilst a narrator provides an appropriately condescending but funny comment. The game uses a system of checkpoints to allow the player to save their progress. There are also collectable items to encourage the players to follow the desired routes. The collectables can then be used in an in-game shop to purchase visual customisations for the player, encouraging further playthroughs. In later stages, the player is also given the ability to utilise a slingshot mechanic to activate switches to open doors within the level. To complement the whimsical nature of the gameplay, at the end of the levels the player is treated to an insightful monologue with a more serious nature reflecting on the experiences of a real wheelchair user.

Extreme Wheelchairing

Available on Google Play Store, iOS App Store and previously Windows Phone, developed and published by independent company DEVM Games, Extreme Wheelchairing (DEVM Games, 2015) provides an action-oriented take on manual wheelchair usage. The game utilises semi realistic landscapes as a backdrop for short time-based navigation challenges. The unique selling point of this game is the control scheme attempts to somewhat mimic actual wheelchair use, using a wheel graphic at either side of the screen which needs to be swiped in a direction to generate movement. The levels are simplistic in nature and the aim is simply to reach the goal in the fastest possible time, there are no collectables or save point systems. Performance is judged on completion time alone, and a rank is given to the user at the end of the level. The handling of the chair physics is not particularly true to life, but when combined with the unique controls it produces an experience which does somewhat resemble wheelchair usage.

Electric Wheelchair Simulator 2020

Available on the Google Play Store and iOS App Store, developed and published by independent company Deep Pocket Studios, Electric Wheelchair Simulator 2020 (Deep Pocket Studios, 2019) provides a rather poorly executed generic wheelchair driving experience. The game uses a realistic city-based environment with low quality models to serve up simple A to B levels where the user needs to avoid static and mobile obstacles. The wheelchair handling is not represented well at all as the chair handles exactly like a small car with front wheel steering. There is no attempt at simulating any aspect of real-world wheelchair controls, with the user being presented with simple up, down, left, right buttons. There are no collectable systems in the game, although the player is awarded money for completing a level which can be spent to unlock an alternative wheelchair appearance. The game utilises a checkpoint system to allow the player to resume after a collision. The main flaw of this game is that it is completely infested with advertisements, to such a degree that it is impossible to enjoy the experience.

2.3 Technical research

For a full description see Appendix N.

2.4 Accessibility

Accessibility Switches

A variety of different devices designed to obtain an input from a physically impaired user. Various examples found at OneSwitch website. (Ellis, 2002)

XBOX Adaptive Controller

The XBOX Adaptive Controller allows the connection of a variety of accessibility switches through 3.5mm jacks and USB ports to create a custom controller experience that is recognised as a standard gamepad by any platforms that utilise XInput (Microsoft, 2018).

Freedom Wing Adapter

As the XBOX Adaptive controller does not support the direct connection of a 9-pin wheelchair joystick connector, the Freedom Wing Adapter was created by the charity AbleGamers and ATMakers which converts the output to USB (Gwaltney, 2020). The plans and code for this device are open source and full instructions are available online (ATMakers, 2020).

3 Design

3.1 Software Development Process

A software development process is the logical definition of stages and the rules governing interactions between them during the lifecycle of a piece of software. This deconstruction of the project allows for much greater focus on specific areas at relevant times, allowing for more clarity and greater productivity for the duration.

3.1.1 Waterfall development

The Waterfall development model, often thought of as the traditional model, is a sequential system where progress flows in a single direction through a series of phases with a different team responsible for each much like a factory assembly line.

Advantages of the Waterfall Model

- The defined separate stages allow single discipline teams to work on their section then immediately switch to a different project in the pipeline.
- By having all the documentation completed up front, there is always a defined specification to work towards.

Disadvantages of the Waterfall Model

- By having single discipline teams working on a section of a project and then handing off, there is never a presence on the project with a vision of the big picture. Problems are often solved in ways easiest for one team which can end up making things far more difficult for the following team(s).
- There is a huge reliance on each stage to be completed correctly, as any errors will not be fixed in the following.
- Even if the requirements have been gathered correctly initially, situations and requirements can change quickly in the business world. As a result of the long delivery time, there is a good chance that whatever was required at the start may no longer be useful by the time the product is ready for deployment.

3.1.2 Agile

Agile software development models take an iterative approach to the development process and often utilise multi-discipline teams which are responsible for the whole lifecycle. Projects are broken down into vertical slices, each featuring a small sub-set of the features intended in the final product. The team then conducts all necessary requirements research, design, implementation, and testing of that slice, before delivering it to be reviewed. If approved the slice is added to the product and work continues to the next slice of features, otherwise the current slice is reworked based on the feedback. The term Agile encompasses many different sub-methods, but the overarching model was officially formulated in 2001 with the creation of The Agile Manifesto which put forward a set of values and principles to work towards.

At first look the Agile values and principles appear to be a direct contradiction of what the waterfall model values, however, one of the creators, Jim Highsmith, clarified that they were simply seeking to balance out the focus between meticulous planning and organisation with that of doing the work to deliver the software the client needs (Highsmith, 2001).

Agile Frameworks

Scrum

Scrum is an agile framework intended for use with small teams, which focuses on producing regular product increments to obtain feedback, driving the direction of development. Development tasks are defined in a backlog list which is then ordered by priority. The main feature of scrum is the concept of dividing up and time-boxing the workload, ensuring that high priority tasks are either completed within a one-to-four-week scrum sprint period or quickly rejected for further clarification of requirements. (Scrum.org, 2020)

Kanban

Kanban utilises a large backlog of work items which are continuously pulled through the stages of workflow. Each workflow stage has a limit to the number of tasks which can be active in it at any one time, helping to ensure that the development team are not swamped with work. Releases in a Kanban system are much more freeform and can occur at a set date, including all the completed features up to that point, or they can take place once a specific feature has been completed (Radigan, 2021).

3.1.3 Selected Model

This project will be developed using Agile methodologies as opposed to the waterfall model, due to the importance of receiving as much feedback as possible from medical professionals. As regular releases will be key to obtaining the most feedback, Scrum will be the intended framework. Since Scrum is intended to operate with a team conducting regular performance and product reviews and this project is solo work, these elements will consist of periods of self-reflection and evaluation, aiming to achieve a similar effect.

3.2 Development Environment

3.2.1 Game Engines

Unity

The Unity game engine operates using a component-based system which offers drag and drop functionality and a primary scripting API using C#, which is converted to more efficient C++ at runtime. Due to this central scripting API, Unity supports building to over 20 different platforms without requiring any changes to the user code, allowing a huge amount of flexibility. Unity focuses on providing a broad range of tools operating across the widest range of platforms, and this is reflected in the statistics as Unity is the preferred engine of choice when dealing with mobile games, as 71% of the top 1,000 mobile games in 2020 were made with it. Across mobile, PC and console platforms, 50% of the games were made in Unity, according to Unity internal data (Unity Technologies, 2021e).

Unreal Engine

The Unreal Engine operates using a component-based system, offering drag and drop functionality and uses a primary scripting language of C++. As a result of being based on C++, Unreal supports building to around 15 different platforms. The focus of the Unreal Engine is high fidelity graphics, photorealistic rendering, and pure performance (Epic Games, 2021).

3.2.2 Code Editors

Visual Studio

Visual Studio by Microsoft is a highly flexible IDE capable of being used to develop using a variety of coding languages and targeting multiple platforms. Included in Visual Studio, Intellisense is Microsoft's intelligent code completion tool which speeds up development by reducing typing errors and offering a selection of automated refactoring operations (Microsoft, 2019).

JetBrains Rider

Rider is an IDE targeted specifically at C# and .NET development, developed by JetBrains. Rider offers enhanced integration with the Unity editor, providing the ability to control editor playback without task switching, coding hints concerning the usage of Unity functions and values, an extended selection of automated refactoring operations, and the ability to highlight code and variable usage within prefabs and scenes (JetBrains, 2021).

3.2.3 Selected Development Environment

After researching the various development options, Unity has been chosen as the main development tool. This is due to the speed of development possible, amount of flexibility offered and previous experience with the software. The JetBrains Rider IDE will be used as the main code editor as the additional integrations with Unity, and advanced refactoring tools should prove extremely useful.

3.3 Target Platform

3.3.1 Virtual Reality

Oculus

There are two variants of the Oculus platform currently, the Quest which is a standalone headset operating on a mobile chipset with 4-6GB of RAM with an Android based OS, and the Rift which needs to be connected to a PC and uses external sensors for tracking. Hardware prices ranges from £300 to £400. Both headset types utilise Touch Controllers, allowing users to intuitively interact with the VR experiences (Oculus, 2020).

Development is possible using Unity and Unreal Engine, and natively using the appropriate SDK package.

The main advantages to the Oculus platform are the unparalleled immersion factor of VR, and the relatively low cost of its hardware compared to the competition.

The main disadvantages are that the hardware is still expensive, and many people experience negative physical side effects when using the systems (Cobb, Nichols, Ramsey, & Wilson, 1999).

3.3.2 Screen Based

Windows PC

The Windows 10 platform has a userbase of over 1 billion, estimated to be a roughly 75% share of the desktop market (Microsoft, 2021). Applications for Windows are often developed using C# and .NET, or for more graphically challenging applications, C++ and DirectX (Windows Developer, 2021).

The advantages of developing for a PC are the flexibility offered in terms of language/tools, and the virtually unlimited processing power available.

The disadvantages are the high cost associated with the hardware needed specifically to play games, and the difficulty of testing with a near infinite number of possible hardware configurations.

WebGL

WebGL is a cross platform web standard based on OpenGL ES, with a royalty free usage licence (The Khronos Group, 2011). It uses an HTML5 Canvas element on a webpage which provides access to the use of GPU accelerated physics and image rendering without the need for additional web browser plugins. The core code when using WebGL is written in JavaScript with the ability to utilise shader code written in OpenGL ES Shading Language.

The main advantage to WebGL is that it can function across virtually any device that has access to a web browser, without the need for specialist hardware or software.

The main disadvantage is that since the core of the code is written in JavaScript, it is not easily ported to platforms other than the web, as they are more likely to use C++/C#.

Android

Android, developed by Google, is the largest mobile platform in the world operating on around 84% of smartphones and 43% of tablet devices (IDC, 2021) (GlobalStats, 2021). The main programming language used for developing native applications is Kotlin, with Java formerly being the focus (Android Developers, 2021). It is also possible to use the Android Native Development Kit (NDK) to utilise C and C++ code (Android Developers, 2020).

The main advantages to the Android platform are size of the potential market, the low barrier of entry to development as no specialised hardware is needed, and the low costs associated with releasing products.

The main disadvantages are, that as the core code is written in Kotlin it is not easily portable to another platform, and that comprehensive testing is extremely difficult due to the wide variety of device configurations which run Android.

iOS

iOS, developed by Apple Inc, is the largest tablet platform in the world with a market share of 56% of all devices, it also has a 16% of the smartphone market (GlobalStats, 2021) (IDC, 2021). Native iOS development uses the Swift and Objective-C programming languages, and programs must be compiled using Xcode on a device running MacOS (Apple Inc, 2021).

The main advantages to the iOS platform are the fact that it generates considerably more revenue through in-app purchases than the Google Play Store (Nelson, 2019), and the fact that development is easier due to only having to consider a limited set of device configurations.

The main disadvantages are that the iOS store operates extremely restrictive guidelines and a screening process on releases, meaning the process can take considerable time, and the fact that expensive Apple hardware is required for the actual development.

3.3.3 Selected Platform

At this stage in the project the application requirements are not fully defined, as a discussion has not taken place with the hospital to assess their needs. Considering this, initial development will target the WebGL platform to have early versions easily accessible for review since no specialist hardware will be needed. As the project will be developed in Unity and written in C#, with the conversion to JavaScript being automated, there should be no issues with switching to an alternative platform later.

4 Production

4.1 First version of wheelchair, reproduction of physics

Before delving too deeply into the project, the aim was to get a prototype of the basic wheelchair movement built as a proof of concept to demonstrate some of the possibilities to the team at the hospital.

4.1.1 Wheelchair dimension modelling

For the initial prototype, the CareCo Easi Go 4 wheeled electric wheelchair was selected as a starting point as it was determined that being a lightweight outdoor chair it would be nimble enough to provide an element of fun. Some basic physical specifications of the chair were obtained from the CareCo website and a block model was created in Unity (Easi go power chair | compact & sturdy | CareCo.2021). Cubes with colliders were used to represent the physical size of the chair, and the overall weight of the chair was specified using the Rigidbody system.

4.1.2 Unity Wheel Colliders

To get the chair moving, Unity's wheel collider components were trialled as a starting point. A tutorial for basic wheel movement was used to create car style motion, which was then intended to be refined to produce realistic wheelchair movement (Unity Technologies, 2021c).

4.1.3 Asset store wheel solutions

The Unity Asset Store was also used to evaluate alternative wheel physics options. At the time of writing the highest rated alternative wheel/vehicle physics packages were Edy's Vehicle Physics (Edy, 2020a) and Vehicle Physics Pro (Edy, 2020b). Simple car style setups were created, and available configuration options explored. Although the contents of the packages were extremely comprehensive, they were unsurprisingly very focused on car-based movement and offered very little extra when it came to reproducing wheelchair movement. As a result, a decision was made to continue working with the default Unity wheel colliders to avoid any unnecessary complications that could be introduced.

4.1.4 Caster wheel/joint operation

On car style vehicles, it is common to have one or more axles with torque being applied that generate forward motion via the drive wheel contact points, and some wheels which can have their facing angle manipulated such that they are responsible for steering (Learn Engineering, 2018). From research in Appendix N , it was found that unlike cars, most wheelchairs do not operate using an axle-based drive system, they have independent drive motors allowing both forward and reverse torque to be applied to individual wheels of the vehicle simultaneously. Steering on a wheelchair does not operate by changing the angles of wheels and is instead based on the ratio of torque applied to the respective drive wheels. Non-drive wheels on the chair are used to provide stability and often operate in a caster like manner allowing a full range of motion.

The first attempt at replicating the caster style movement was based on the idea of using Unity’s hinge joint with unrestricted rotation about a specific axis to allow an attached wheel collider to pivot. Unfortunately, this interpretation did not translate into Unity’s physics system and strange behaviour occurred where the wheel collider would clip into hinge joint, resulting in extreme forces being applied and chair being catapulted into the air.

Further research was conducted into this issue, but unfortunately no solution was forthcoming. A workaround was implemented, removing the hinge joint completely, and using wheel colliders fixed in place with all friction interactions removed from them. This allowed the wheels to provide stability to the chair but meant that they were essentially just sliding across surfaces. This was not an ideal representation of caster wheel operation, as in reality some resistance is felt by the wheelchair user when changing directions, but at this stage of the project it was considered an acceptable compromise.

4.1.5 Development of motor movement

As motor operation was crucial to the driving experience, it was decided to attempt to use unit tests to define the expected behaviour. Research was undertaken into the application of tests within the Unity environment (McMenamin, 2019).

The basic design was that a vector2 input would be received by the WheelchairController class, which would populate private fields with the values. Then on the next FixedUpdate, torque values would be calculated and applied to the respective motors. A utility class that simplified the use of reflection was created which allowed the testing of the input values being received correctly.

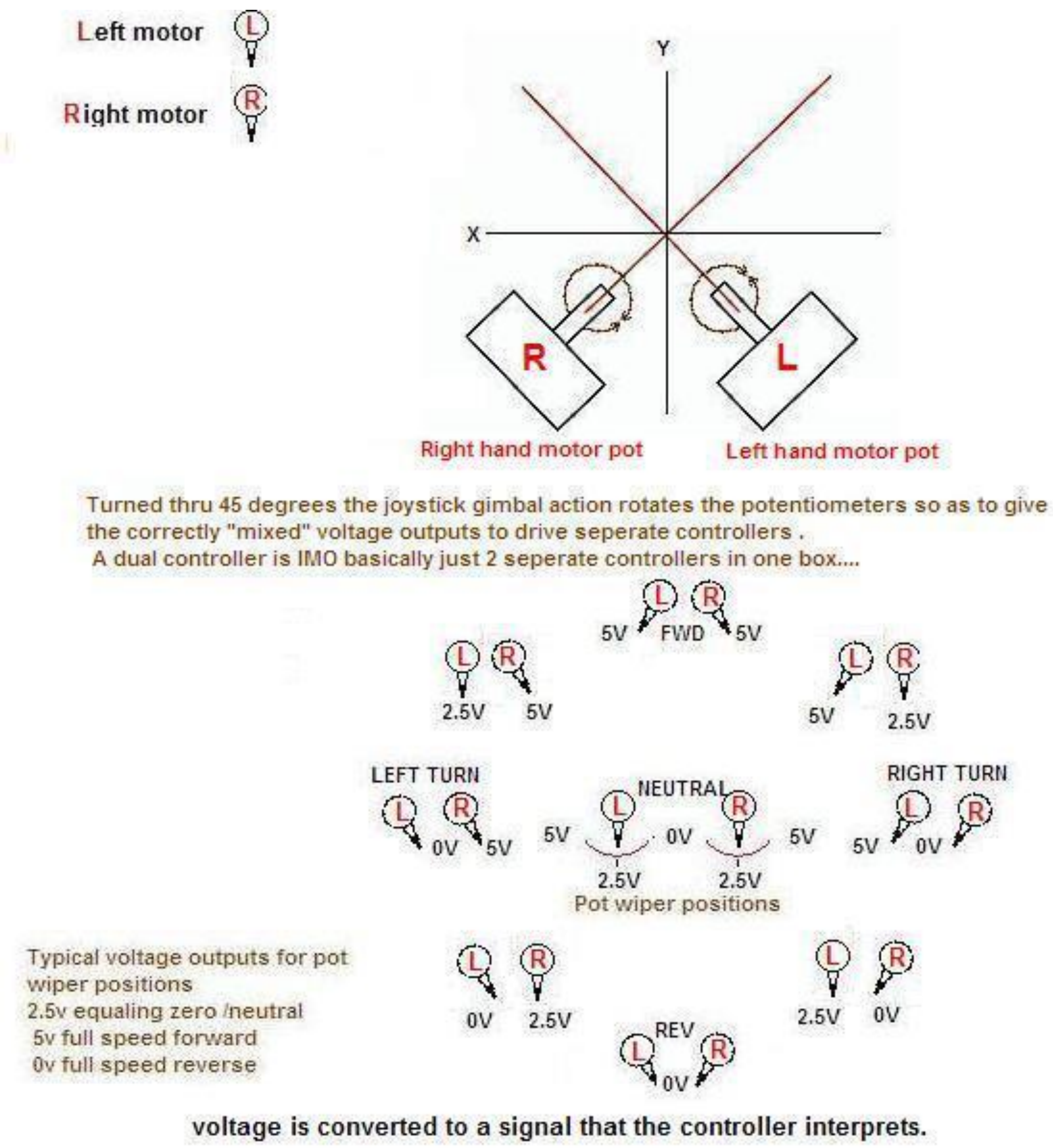

Figure 4-1 Wheelchair joystick/drive motor mix

The percentage torque values were calculated by multiplying the magnitude of the vector2 by a value relative to the amount of voltage that would be sent through to the motor in a real wheelchair according to Figure 4-1 (woodygb, 2012). Unit tests were also implemented to ensure these torque values were being calculated correctly.

When applying torque at a percentage of max rpm relative to throttle input, there were issues where the wheels would continue to increase their rpm past the maximum, resulting in the chair bouncing around before eventually flipping. To offset this, a workaround was applied which used the percentage value to sample an animation curve with a linear falloff. This resulted in much less torque being applied at high rpm values and fixed the issue.

4.2 Basic Controls/UI/Functionality

To create some basic functionality for testing purposes, an on-screen joystick was sourced from the Lean GUI package on the Unity Asset Store and added to a canvas object (Wilkes, 2021). The action of moving the joystick handle with mouse input was linked to providing a vector 2 value to the WheelchairController component, which in turn translated into torque values for the motors and moved the chair.

A simple level was crafted using a single plane to represent the ground, some angled planes to act as ramp objects, and some appropriately sized cubes to represent kerbs. This allowed testing the proof of concept of the movement system.

A UI button was also added to the canvas object to reset the chair in the case of a tip or fall. At this stage of the project, this simply placed the chair back at the origin point of the world by modifying its transform position and rotation.

4.3 Prototype demonstration review with Hospital

The prototype was presented to the hospital and discussions took place concerning their vision for the product, a summary of the meeting can be found in Appendix E.

The initial feedback received was good, and it was apparent that the basic form of the application was aligned to what they had envisioned. It was pointed out that the 4-wheeled wheelchair that was used for the prototype was not a model familiar to the ATP, and their patients would be using a much more heavy-duty chair. The models suggested were the Quickie Q400 and the Quickie Salsa M2, both of which used a 6-wheel, mid wheel drive operation and so handled quite differently. During the discussions it was determined that the preferred usage environment was intended to be unsupervised in the patient's own home. As a result, deploying the application to a VR platform was ruled out, as there would be issues with requiring users to obtain expensive technology, and potential safety issues with its operation unsupervised. The main aim then became the production of a mobile application for use on tablet devices as many users already had those for communication purposes. As there was no access to Apple hardware at the time, the target platform for the project going forward was determined to be Android.

4.4 Set up of cloud builds/remote deploy

As it was previously decided to attempt to follow the Scrum methodology and produce frequent product increments for user testing, and with COVID lockdown restricting meeting in-person and access to hardware, it was determined that the easiest way to ensure access to the software remotely would be to create a version playable through a simple web browser. This process is simple enough when using the Unity engine, as it is just a case of selecting the platform as WebGL, with hardly any changes required to the code itself.

To reduce the potential amount of time spent on having to repeatedly build and deploy to the web, it was decided to implement a system of Continuous Delivery. As a Unity Pro subscriber, the option of utilising the Unity Cloud Build System was available. This system allows the linking of a source control repository to a Unity account and the specification a branch to be monitored for changes. Once changes are detected on the branch, Unity's cloud servers pull the changes, build the project to pre-defined specifications, and provide a link to download the executable. A staging branch was created on the GitLab repository to be used for this purpose.

To handle the actual deployment, a new URL could have provided to the hospital each time a build completed, but it was decided to employ a more elegant solution using webhooks to update a static address on my personal webspace. With no previous direct experience of webhooks, a tutorial from Triplus Tutorials was used to get it set up (Triplus, 2016). This solution worked well and meant that a single URL could be supplied to the hospital, allowing them to always test the latest version without any additional hassle.

Application of the solution was not without its issues. One problem area was the Universal Render Pipeline (URP) shaders not being built correctly during the cloud build. It was discovered that the package manifest json was not being included in the repository, meaning cloud builds did not know that URP was being used. Pushing the required file up to the remote repository fixed the problem.

4.5 First playtest review with hospital

With the cloud build and remote deployment set up, the ATPs were provided the access URL and given the chance to try the application themselves. For full comments see Appendix F. This session confirmed that the mouse controls worked correctly when using the on-screen joystick, which meant that a wheelchair joystick operating in mouse emulation mode should also be compatible. This was promising feedback, but ultimately the aim was to support joystick input as close to the real experience as possible and not rely on mouse emulation. Lots of bugs and unfinished areas were pointed out, but at this stage those were expected to be present.

4.6 Expanding input options.

With a basic proof of concept for the chair behaviour created, the focus shifted towards supporting different types of input devices with a view to eventually working with an actual wheelchair joystick controller.

4.6.1 Research into default Unity input system and multi device support

Upon examination of the standard Input Manager offered by Unity, it became obvious that there would be no easy way to handle multiple devices. The standard way of communicating required every device type to have their buttons and keys specifically mapped to commands at compilation time. This was further complicated by the requirement for mobile device touch screen controls with different touch variations to also be bound separately (Unity Technologies, 2020b). When dealing with real wheelchair joystick controllers, this type of static control binding would be extremely restrictive and not ideal at all.

4.6.2 Asset Store input solutions

The Unity Asset store was again evaluated for potential solutions and the top-rated utility asset, Rewired, was trialled (Guavaman Enterprises, 2021). Rewired shifts the onus from static binding towards a system of Action Maps, allowing a desired outcome command to be defined to a family of control inputs rather than each device specifically. Runtime rebinding of these action maps is also supported, allowing the possibility of control remapping at the application level rather than having to use an input wrapper for more obscure devices.

4.6.3 Research into new Unity input system

Recently, Unity have been developing a new input system that is available as a free of charge preview package via the package manager. The new system operates in a similar way to the Rewired extension, focusing on the creation of Action Maps and their binding to a family of controls. Unity provided sample implementations were explored and tested, along with viewing of supplementary video walkthroughs from their Unite Now conferences to build up an understanding of the system (Hougaard & Touch, 2020). As this was available free of charge and provided as much flexibility as Rewired, it was decided to continue development using it.

4.6.4 Implementing basic multi device controls

An Action Map was initially created which defined a movement action taking in a two-dimensional value, and a confirm action which utilised a single button press. The movement was attached to the default movement controls across most devices, and the confirm button was attached to the default start control. The on-screen controls were modified to trigger the respective gamepad actions rather than interacting with the WheelchairController directly. In this case, movement was defined as Left Joystick Position, and confirm as Start button.

A custom JoystickInput class was created which hooked onto the specific commands from the input system and assigned them to actions in-game. However, this was found to be too restrictive when considering key rebinding, and the system was reworked to utilise Unity's inbuilt solution of a PlayerInput component.

4.6.5 Dropping of Unit Testing Priority

The addition of the input system added a lot of complexity in terms of unit testing, dealing with mock objects and Monobehaviour slowed development considerably, and a lack of testing experience started to show. With basic movement covered by the test suite, it was decided that the best option to maintain development speed would be to halt further work on automated unit and integration testing for the near future.

4.7 Second version of wheelchair, Quickie M2

In response to feedback received from the hospital at the prototype demonstration, it was decided to produce a new model of wheelchair that better represented the type of chair hospital users would be familiar with. The model selected was the Quickie Salsa M2, as it was the most used chair at the time according to the ATP. Research was conducted into the specifications of the chair, with dimensions and technical information gathered from the user manual (Quickie, 2019b) and spare parts catalogue (Quickie, 2019a). In lieu of being unable to visit the hospital to physically interact with and inspect the chair due to COVID-19 lockdown restrictions, a variety of video evidence of the chair being operated was sourced to improve understanding (HANDICAP Info Centrum, 2015), (Sunrise Medical Europe, 2014), (Lewis, 2018).

A new block model was created in line with the chair specifications and a second set of caster wheels was added to the rear to reproduce the 6-wheel configuration. The motor torque and rpm values were set according to the actual specifications, although the torque curve remained as a linear fall off. Unfortunately, the central wheel setup combined with the increased weight of the chair produced issues of the wheels sliding when attempting to traverse ramps. Attempts to resolve this involved experimenting with increasing the wheel friction values, stiffness and motor power. Ultimately no solution that represented the real chair behaviour exactly was found. A workaround was arrived at by increasing the size of the wheels and having the motor able to deliver a greater maximum rpm. These changes allowed the chair to exhibit similar behaviour to the real chair and were an acceptable compromise.

4.8 Level loading framework

In preparation for the introduction of a variety of playable levels, a placeholder menu framework was created. This allowed the user to interact with UI buttons to enter/exit the application and proceed to a screen that provided a list of the available levels.

For each level, a name, text description, reference to a sprite containing a preview image for the level, and reference to the scene containing the level layout were stored within a LevelData scriptable object. A GameData scriptable object then held an array of LevelData objects and an array of the available wheelchair prefabs (for future wheelchair selection options). The level selection screen featured a LevelSelectionDisplay component that read the current GameData object, iterated through the available LevelData and instantiated a visual prefab with a LevelInfoDisplay component for each entry. Using an Init function, each LevelData was passed to the LevelInfoDisplay component, which in turn populated the relevant UI sections of the prefab instance. These prefabs were then parented to a Scroll Rect container, creating a navigable list of playable levels.

Each menu screen had a MenuController component which communicated with a global GameManager object, signalling for a state change, and passing through a reference to the scene to switch to. The level loading was done using the Unity Addressable system, as having used the system previously, it has been found to provide a manageable way to reduce memory usage on lower powered mobile devices.

4.9 Introduction of gamification features

With the wheelchair operation at an acceptable level and the framework established to load levels, attention shifted towards creating an actual game experience. Research was undertaken into a variety of gamification options, resulting in a basic Game Design Document and some Use Case diagrams being produced, see Appendix K., Appendix L, and Appendix M.

The first thing to address was allowing the player to complete a level. It was decided that the game would use an A to B style level structure, and so a visual representation of an 'End Zone' was put together using some prebuilt components. In terms of behaviour, it was decided that each level may have differing requirements for ending the level, so simply entering the zone collider would not be enough. A system was designed using a base class CompletionRequirement that could be queried for its completion state, and subclass variants would specify the required behaviour to satisfy a completion condition. For example, the PlayerParkedCheck component checked the player's velocity every FixedUpdate, and triggered a RequirementCompleted event as soon as it returned to zero. An EndZone component checked at the start of a level for any attached CompletionRequirement type components, and, whenever a RequirementCompleted event was triggered, the status of all of them was queried. When all the CompletionRequirement components were in the completed state, the EndZone triggered a LevelCompleted event, which was then picked up by a LevelManager and acted upon accordingly.

The next thing to address was the judging of player progress. It was decided that in this instance a simple timer which recorded how long it took the player to fulfil the level completion requirements would suffice. This was displayed in real-time on the screen during play, and more prominently on the end of level screen.

To introduce a more game like feel, the introduction of collectable items followed. A recognisable coin style model was used to create the visual representation of the collectables. The behaviour of the collectables was initially quite simple, each collectable object possessed a Collectable class containing a field for its own identifier number and some default behaviour to respond to being collided with. In a similar style to the completion requirements, upon scene start a CollectableManager class searched the scene for all collectable components present and stored references to them in a dictionary using their id as the key. This was done in anticipation of the future task of serialising and saving the status of which collectables had been collected. The number of collectables gathered was also added to the end of level screen as an additional performance metric.

Finally, players needed some way to continue their level progress during play in the event of a tip or fall. This manifested in a checkpoint style system as a natural evolution of the existing chair reset mechanic. Instead of a single reset location, it was decided that there should be several key places throughout the levels to which the player could return to. Checkpoints were designed to be activated when the player encountered their collider. Once a checkpoint was activated, previous checkpoints were added to a pool of ‘saved’ objects whose state could no longer be modified, and further attempts to reset the chair would return the player to the last interacted checkpoint’s position. This unfortunately introduced complications with the collectables and the need to reset their states too. To resolve the issue, the collectables and checkpoints were modified to utilise the same base behaviour, which used three collections to manage their state, active objects, interacted objects and saved objects. In this modified structure, when an object was interacted with, it was placed into the interacted objects collection. If the object were a checkpoint type, all types of previously interacted objects would be moved into their respective saved object collection. At any point in the level, an attempt to reset the chair would return all interacted objects into their respective active collections.

In response to feedback from the ATP, a pause feature was also added at this stage. This simply stopped the timer, and disabled player controls on the wheelchair object.

4.10 Level design + production

Before designing the layout of the individual levels, greater research was undertaken into the skills needed to successfully drive. Observing the existing Wheelchair Skills Test process was extremely helpful in building an understanding of the type of skill-based assessments currently used (Wheelchair Skills Program, 2018). It was also enlightening to hear about the wheelchair driving process from the point of view of a driving instructor and offered additional considerations in the design process (Perkins eLearning, 2016). A selection of wheelchair games for children was also found to be very insightful and provided ideas for further gamification (Gympanzees, 2020).

Using the knowledge gained from the research, some level layouts were sketched out in preparation for building them in Unity.

4.10.1 Research into level building tools

To facilitate building the level layouts in Unity it was decided to utilise the optional Unity packages Progrids and Probuilder. Research was undertaken to gain an understanding of how to operate the systems (Brackeys, 2019) (Unity, 2018).

4.10.2 Building levels

Custom ramp objects and appropriately sized landing platforms were created, matching the current legally required specifications (Northeast Rehabilitation Health Network, 2008) (Nurture Group, 2019) (Basingstoke and Deane Borough Council, 2004). Additional prebuilt models were included to enhance the games' feel (Synty Studios, 2020). A small number of level scenes were then assembled using the various prefabs to match the designs. A LevelData object was then created for each level and a reference to it was added to the GameData object.

4.11 Second playtest review with hospital

At the second formal play test of the application, the ATPs got to experience the first few game levels and associated mechanics. For full comments see Appendix G. The consensus was that the app successfully represented the appropriate level of care needed when driving a real wheelchair. The checkpoint system was well received, although an issue was raised regarding disorientation as the chair was reset back to a safe position. An issue with the end of level screen was also raised, with users getting stuck on it as the exit button was not clear and obvious. The ability to pause the level and exit without completion were also appreciated quality of life improvements. The collectables were not specifically mentioned at this stage, but it was observed that they were successfully helping users navigate through the levels. Direct usage of a joystick was not possible at this stage as they defaulted to mouse style input, however, the belief is that when connected through an Xbox Adaptive Controller they will behave as a gamepad analogue stick and provide their full range of motion. The level completion timer was well received and generally accepted as the best way to judge user performance. A suggestion was made to store the completion times, so that a user could look back on their progress.

4.12 User experience upgrades

In response to the feedback concerning disorientation when the chair reset to a checkpoint, it was decided to redesign the experience entirely. Inspiration was taken from Mario Kart and the way players are replaced on the track (ProsafiaGaming, 2017). The intent was to pause time and zoom the camera out into a raised third person perspective, allowing the user to view the crash situation, then slowly move the chair back onto the checkpoint, and finally zoom the camera back in to first person view and restart the timer.

As Unity had recently introduced a new camera system, Cinemachine (Unity Technologies, 2021a), it was researched to determine its suitability for this situation. A prototype of a controllable orbit style camera was created with information from the Unity Learn documentation with a view to being included in the future (Unity Technologies, 2021d).

The final implementation of the solution consisted of converting the first-person camera into a Cinemachine Virtual Camera, creating a second Virtual Camera at the third-person angle, and adding a Cinemachine Brain to the scene. Taking inspiration from a YouTube video, a CameraController component was created to alter the priorities on each camera in response to the chair reset event, allowing the brain to automatically blend between the two cameras (samyam, 2020).

Additionally, in response to the feedback about users getting stuck on the end of level screen, the exit button was made larger and more obvious.

4.13 Third playtest review with hospital

For full comments see Appendix H. The feedback from this session was extremely positive, with both the ATP and SUR stating that they enjoyed the game and that they considered it to be representative of the wheelchair driving experience. The change made to the ‘reset to checkpoint’ interaction was well received, with the ATP stating that the overhead view allowed a better understanding of the environment resulting in less disorientation. Many suggestions for improvements were made in the session, inclusion of sound effects, better visuals, improved user interface with symbols to help non literate users, a leader board of completion times to encourage competition, levels with mobile obstacles, a help page, and a football style level. An Android build was also requested for testing by the ATP and SUR.

4.14 Android device controls

Unable to access a wheelchair joystick and Xbox Adaptive Controller to verify functionality when paired, development was forced to continue with the assumption that standard gamepad behaviour would be produced. The focus was then switched onto testing gamepad behaviour on an Android device. A Bluetooth gamepad was connected to an Android device and manual testing was undertaken. The controls were initially unresponsive, and during debugging it was discovered that the gamepad control actions were not being loaded. This was due to the ‘Touch’ control scheme not having a gamepad input device specified as being usable. To ensure no further issues would arise on other build targets an optional gamepad device was added to every control scheme. Other than that, both gamepad and touchscreen controls functioned as expected, menus were usable, pause functionality worked, and the thumb stick provided a pleasing driving experience.

4.15 Introducing Mobile Obstacles

To implement the mobile obstacles, it was decided to use Unity’s NavMesh system as from previous experience it was considered relatively easy to implement. Unity Learn documentation was consulted as a refresher on the intricacies of the system (Unity Technologies & Brackeys, 2020).

A humanoid model from the Polygon Prototype Pack (Synty Studios, 2020) was used as the avatar, with the Unity 3rd Person Character Controller component (Unity Technologies, 2020a) driven by root motion animations as the main method of locomotion. Individual character animations were sourced from Mixamo (Adobe Systems Incorporated, 2020) and combined in a blend tree. There was a problem using the included model when rigging in Mixamo, the feet bones were bending at odd angles. From further research (CosmicBoy, 2019), it was discovered Synty Studios provided an alternate model to use for rigging purposes which was obtained via a hyperlink on a tutorial video (Synty Studios, 2019).

Once the animations were working correctly, a selection of Gameobjects were placed in the world to act as waypoints. A component was then created which referenced those positions, selecting them and moving the mobile object towards them sequentially, creating a patrolling effect.

With movement working correctly, work began on creating interactions with the player. The intent was to create a system where the humanoid model would stop moving when collided with, switch to a ragdoll, and then comically fall to the floor. Research started into this area and a basic prototype was created, but it was not finished in time to be included in the final product (Unity Technologies, 2021b).

4.16 Polish

In response to feedback from the last playtest, the menu visuals were improved with a custom background image (Kachaev, 2019) and better button images (Nayrissa, 2018), icons were added for non-literate users (GDev, 2016), and custom fonts were added

(Dziedzic, 2010) (Impallari Type, 2012). Sounds were added to the gameplay events of collecting a collectable, reaching a checkpoint, resetting the chair to a checkpoint, and reaching the end goal to enhance the experience (Dustyroom, 2019). To further enhance the gameplay events, the coin pickups were given an animated bounce and spin motion, and a transparency effect was added to them when collected. The addition of background music in the menus and during play was trialled but rejected as it was considered too distracting.

There were also slight tweaks to motor torque values and falloff curve levels to improve responsiveness.

4.17 User system and saving

Work was started on a system to record the level completion times and serialise out the data on a per user basis. Unfortunately, this was not completed before the end of the project and was not included in the final deliverable.

4.18 Fourth playtest review with hospital

For full comments see Appendix I. The feedback from this session was again very positive. SUR indicated that the responsiveness of the joystick was improved, and the visual changes were appealing. SUR rated the application 9 out of 10. SUR suggested that a speed toggle be introduced in the future, as found on real chairs, to toggle between outdoor and indoor power modes. SUR also requested to feature the game in a disability related podcast that they are involved with. ATP felt the visual improvements made the application feel a lot easier to interact with, the sounds improved the gameplay experience, and the moving obstacles were a nice addition. The ATP also found that the game functioned well on Android devices, with the on-screen joystick feeling much more realistic than when using a wheelchair joystick in mouse operating mode.

5 Evaluation

5.1 Critical Reflection

5.1.1 Evaluation of the research

The main aims for the research aspect of this project were to investigate real-world wheelchair operation, existing solutions that offer a wheelchair driving experience, and the possibility of connecting a wheelchair joystick to act as the game controller. The researcher felt that they learnt a great deal about the operation of both powered and manual wheelchairs from the research, covering everything from the construction of homebrew powered wheelchairs to examining the skills needed for the completion of the Wheelchair Skills Test. They do, however, feel that without the lockdown restrictions imposed because of COVID-19, they would have been able to go even more in depth by having some hands-on experience driving a real wheelchair and access to additional hardware. Given the circumstances though, they are satisfied that they have done as much as they could.

5.1.2 Evaluation of the deliverable.

The main aim of the project deliverable was to produce an experience comparable to driving a powered wheelchair with the inclusion of some gamification, allowing users to practice driving without the associated risks.

From the feedback received over the course of the project and from the feedback summary in Appendix J, the deliverable successfully recreates the experience of driving a powered wheelchair and would enable users to develop their real-world driving skills, in the opinion of both Assistive Technology Professionals and a Service User Representative.

Ideally users would be able to use a real wheelchair joystick to control the experience, and theoretically it should be possible with the combined use of a Freedom Wing Adapter and an Xbox Adaptive controller. Unfortunately, there was no access to the hardware to be able to verify the functionality.

In terms of gamification, there is a small but functional set of game style features in the application. The level timer, collectables and checkpoint save system serve to reinforce that the product is indeed a game rather than a simulator in its current state. The timer was an effective way of triggering intrinsic motivation of the user to continue playing, determined to beat their previous time. However, the researcher feels that the systems could be expanded in the future to provide an even more in depth and enjoyable game experience.

5.1.3 Evaluation of the project management.

The original aim of the project management was to operate a Scrum style system, producing regular product increments for review by hospital staff and iterating on those to perfect the product. Initially this arrangement worked well, and a couple of iterations were produced and reviewed, showing proof of concept, and then improved wheelchair handling. Unfortunately, as the project continued it became apparent that the system was unsustainable as sprint velocity dropped considerably and work began to get backed up.

Examining this, the issues began to arise as other project deadlines approached and attention got diverted onto more pressing tasks. This may have been down to an over scoping on the amount of work intended on this project, or an underestimation of the amount of work needed on other assignments. In hindsight, it was probably a case of both.

The workload problem really became an issue during the Christmas break period, as the closure of schools due to COVID-19 meant additional demands were placed on the researcher’s time with having both of their children constantly at home. Unfortunately, there no realistic way the situation could have been avoided, but mitigation of the impact was attempted by moving their work area to a more isolated location and rescheduling some work to later in the evenings after the children had gone to bed.

At the end of the Christmas holiday period, the researcher was extremely stressed about falling behind with their workload expectations and was convinced that the project was a failure. A meeting was scheduled with the project supervisor, where reassurances were provided that the project was in an acceptable state, and suggestions were made to evaluate how best to utilise the remining time. On reflection, although the COVID-19 situation did not help matters, there had been a gross overestimation of what could be achieved in the available timeframe, resulting in an increased amount of pressure to produce something far beyond the scope of a simple prototype.

Following the discussion with the project supervisor, the workflow of the project was reorganised to operate under a Kanban system, removing the growing pressure of falling behind arbitrary weekly deadlines and allowing the focus to be solely on task completion. This switch worked wonders for the researcher’s mental health, and in retrospect the problems should have been seen and acted upon much earlier. After the switch, a couple of further product increments were produced and reviewed by the hospital, allowing for more changes based on their feedback.

Overall, the researcher feels that the project management has worked sufficiently to achieve what they had originally set out to do. They had wanted to produce multiple product increments throughout the project for review and that has been done successfully on four occasions with the feedback gained proving invaluable in shaping the product. If they had the time to do the project again, they would operate on the Kanban framework from the outset as it proved to be far more flexible for someone with caring responsibilities, and they believe that additional flexibility would be beneficial even in non-pandemic times.

5.2 Professional and Ethical Concerns

At the beginning of the project, great consideration was given to the structure of development and testing so as not to interact too heavily with professional regulations and ethical issues. To comply with General Data Protection Regulation (GDPR), data obtained through the application was only ever stored on the user's device. No analytics were performed using the data, and nothing identifiable was recorded. Testing and evaluation of the application was done by qualified Assistive Technology Professionals, ensuring no vulnerable people were subjected to potential risk.

In the future there may be a need to consider GDPR as a leader board feature has been frequently requested, which would potentially need to store level completion data on a remote server. Also, another feature which was mentioned was the ability to replay a user's performance on a level allowing them to see their mistakes which would require the storage of their input data during play sessions.

Further complicating the implementation of these features is the fact that the intended end users of the application may be children or vulnerable adults, and so a full risk assessment would be needed.

5.3 Personal and Professional Development

The researcher feels that a great deal was learnt during this project. Greater empathy and respect towards wheelchair users were cultivated when learning in detail about some of the types of struggles they face, how often those situations are encountered, and the extent of the skills needed to drive safely. From an engineering perspective, the researcher built up knowledge of the construction and operation of wheelchairs, the physics involved in the driving process, and some of the assistive technology options available. From a programming perspective, they learnt how to operate some of the newer Unity features and refreshed their knowledge on older ones.

The researcher also learnt a considerable amount about their own shortcomings. They realised that unit testing gets quite complicated when dealing with multiple dependencies, and they did not have the skill or knowledge to make use of it in a large project. They will strive to develop this skill in the future, by researching and practicing Test Driven Development until they are comfortable introducing it into smaller projects before attempting any further large-scale integration. The researcher learnt that they need to temper their initial expectations and not over scope, in the future they will aim for a much smaller viable product before expanding upon that with considerable stretch goals. In relation to that, the researcher learnt that they need to give more consideration to their mental health needs and must avoid placing unnecessary pressure upon themselves in future project work.

6 Conclusion

6.1 Summary

This project has investigated real-world wheelchair operation, the skills required to be able to drive one successfully, the requirements needed to produce a virtual wheelchair experience, and ways to teach the necessary driving skills in a virtual environment. The risk of serious injury whilst operating a wheelchair was a key factor in the desire to find a solution that allows users to practice their driving skills in a safe environment. This project supports the idea that a virtual environment can be used as a supplementary tool for gaining skills and confidence when driving a powered wheelchair. The findings also support the idea that gamification can be used as a tool to increase user engagement with the medium. The project scope was limited by the restrictions on time, and access to resources imposed by COVID-19.

6.2 Future Improvements

For further work, this application could be improved with a larger selection of skill-based levels, focusing on more aspects of wheelchair driving, such as navigating doors and small gaps. The addition of an open-world level, encouraging discovery, would provide an alternate method of learning driven by the intrinsic curiosity to explore. The environment was found to be slightly disorienting, as such, higher fidelity more varied landscapes would be a great improvement.

In terms of gamification, the introduction of an in-game shop style interface allowing the user to spend their collectable items in exchange for chair customisation options would be a good way to add some replay value and improve engagement. As requested by the ATPs, a scoreboard and online leader board system could help to improve engagement, as it would introduce competition.

A help section for users would also be a good addition, although confirming joystick controller operation should be factored into the contents.

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Appendix A – Project Specification

PROJECT SPECIFICATION - Project (Technical Computing) 2020/21

Student:	**Nico Caruana**
Date:	**20th October 2020**
Supervisor:	**Peter O'Neill**
Degree Course:	**BSc (Hons) Computer Science for Games**
Title of Project:	**A gamified application, which allows the user to safely practice the skills necessary to drive an electric wheelchair.**

Elaboration

For many people with mobility issues an electric wheelchair is a necessity. However, learning to drive one can be a daunting prospect. The learning curve can be quite steep depending on the user's confidence in using technology; mistakes and accidents can be potentially painful and/or costly.
The Assistive Technology Team at Barnsley Hospital have requested that an application be developed to provide the user with a safe way to practice their wheelchair driving skills. Initial discussions clarified that the team would like the application to operate in a game-like manner encouraging self-directed play in a home environment, rather than a specialist tool to be used specifically within the department. The application would ideally provide a close to real-life experience for the user, but they are willing to compromise on realism provided the underlying skills are being taught. The application would ideally be able to be controlled using a real wheelchair input device, such as a joystick, or switch/es. Common obstacles such as Kerbs, Roads, Stairs, and other objects should be incorporated into the experience. The team would also like it if realistic effects of driving over different surfaces types and cambers could be included, but these are not necessary.
This project aims to build upon that request and explore whether a gaming experience could be considered a valuable tool in the process of learning to drive an electric wheelchair.

Project Aims

- Investigate real-world wheelchair operation, existing wheelchair training solutions and other applications that offer a simulation experience.
- Investigate the possibility of implementing an actual wheelchair joystick as the application controller.
- Implement the research findings into a realistic driving experience and include gamification.
- Improve the application experience using feedback from Assistive Technology Professionals.

Project deliverable(s)

I will develop an application that provides a game-like experience which will allow the user to practice some of the skills required when driving an electric wheelchair.
This application will be targeted towards low powered mobile devices to ensure usability by the maximum possible target audience. Initial development will be for the android platform as access to Apple hardware is limited.
The application experience will:

- Offer a semi-realistic wheelchair driving experience to the user.
- Provide situations with static obstacles to allow basic control practice.

- Provide situations with moving obstacles to best represent real world situations.
- Utilise gamification to improve engagement amongst target audience.

I will manage the project using the SCRUM framework as a baseline for defining and allocating workload. I will also set up a release pipeline that allows for continuous delivery to a remote host, allowing product testing to be much more dynamic. I also intend to use unit and integration tests as much as possible to ensure that the application is as bug free as possible due to the nature of its intended audience in the long term.

Action plan

Action	Suggested Completion Date
Find project supervisor	9th October 2020
Submit project specification and ethics forms	23rd October 2020
Set up project management solution	23rd October 2020
Research into game engine technologies	23rd October 2020
Set up development environment / game engine	23rd October 2020
Research into continuous deployment pipelines	23rd October 2020
Set up continuous deployment solution	23rd October 2020
Research other examples of wheelchair training software.	Ongoing throughout the project and beyond.
Produce first version of the app that contains basic wheelchair movement as proof of concept	16th October 2020
Research physics interactions associated with driving an electric wheelchair	23rd October 2020
Research different wheelchair models and their handling characteristics	23rd October 2020
Produce second version of the app with improved wheelchair physics	30th October 2020
Research input methods available on devices with a view to enabling control with an actual wheelchair joystick controller.	6th November 2020
Produce third version of the app that is controllable with a generic gamepad device.	13th November 2020
Research wheelchair users' experiences and identify situations determined most difficult.	Ongoing throughout duration of the project.
Research government regulations on wheelchair use with a view to incorporate any legal restrictions.	Ongoing throughout duration of the project.
Research other examples of existing driving simulation games.	Ongoing throughout duration of the project.
Research gamification techniques	Ongoing throughout duration of the project.
Produce fourth version of the app with a small selection of gamified levels	11th December 2020
Continue to refine application based on feedback, and research additional areas where necessary	Ongoing throughout duration of the project.
Submit Information Review	4th December 2020
Submit provisional contents page	19th February 2021
Draft critical evaluation	19th March 2021
Submit report to TurnItIn	15th April 2021
Submit Report to Blackboard	15th April 2021
Demonstration of the work	Before 29th April 2021

BCS Code of Conduct

I confirm that I have successfully completed the BCS code of conduct on-line test with a mark of 70% or above. This is a condition of completing the Project (Technical Computing) module. **Signature: Nico Caruana**

Publication of Work

I confirm that I understand the "Guidance on Publication Procedures" as described on the Bb site for the module. **Signature: Nico Caruana**

GDPR

I confirm that I will use the "Participant Information Sheet" as a basis for any survey, questionnaire or participant testing materials. This form is available on the Bb site for the module and as an appendix in the handbook. **Signature: Nico Caruana**

Appendix B – Ethics Form

Sheffield
Hallam
University

UREC2 RESEARCH ETHICS PROFORMA FOR STUDENTS UNDERTAKING LOW RISK PROJECTS WITH HUMAN PARTICIPANTS

This form is designed to help students and their supervisors to complete an ethical scrutiny of proposed research. The University Research Ethics Policy should be consulted before completing the form. The initial questions are there to check that completion of the UREC 2 is appropriate for this study. The final responsibility for ensuring that ethical research practices are followed rests with the supervisor for student research.

Note that students and staff are responsible for making suitable arrangements to ensure compliance with the General Data Protection Act (GDPR). This involves informing participants about the legal basis for the research, including a link to the University research data privacy statement and providing details of who to complain to if participants have issues about how their data was handled or how they were treated (full details in module handbooks). In addition, the act requires data to be kept securely and the identity of participants to be anonymized. They are also responsible for following SHU guidelines about data encryption and research data management. Information on the Ethics Website

The form also enables the University and College to keep a record confirming that research conducted has been subjected to ethical scrutiny.

The form may be completed by the student and the supervisor and/or module leader (as applicable). In all cases, it should be counter-signed by the supervisor and/or module leader, and kept as a record showing that ethical scrutiny has occurred. Some courses may require additional scrutiny. Students should retain a copy for inclusion in their research projects, and a copy should be uploaded to the relevant module Blackboard site.

Please note that it may be necessary to conduct a health and safety risk assessment for the proposed research. Further information can be obtained from the College Health and Safety Service.

Checklist Questions to ensure that this is the correct form

1. Health Related Research with the NHS or Her Majesty's Prison and Probation Service (HMPPS)or with participants unable to provide informed consent

Question	Yes/No
1. Does the research involve? • Patients recruited because of their past or present use of the NHS	No
• Relatives/carers of patients recruited because of their past or present use of the NHS	No
• Access to data, organs, or other bodily material of past or present NHS patients	No
• Foetal material and IVF involving NHS patients	No
• The recently dead in NHS premises	No
• Prisoners or others within the criminal justice system recruited for health-related research*	No
• Police, court officials, prisoners, or others within the criminal justice system*	No
• Participants who are unable to provide informed consent due to their incapacity even if the project is not health related	No
2. Is this a research project as opposed to service evaluation or audit? *For NHS definitions of research etc. please see the following website*	Yes

http://www.hra.nhs.uk/documents/2013/09/defining-research.pdf	

If you have answered **YES** to questions **1 & 2** then you **MUST** seek the appropriate external approvals from the NHS, Her Majesty's Prison and Probation Service (HMPPS) under their independent Research Governance schemes. Further information is provided below.
https://www.myresearchproject.org.uk

NB College Teaching Programme Research Ethics Committees (CTPRECS) provide Independent Scientific Review for NHS or HMPPS research and initial scrutiny for ethics applications as required for university sponsorship of the research. Applicants can use the IRAS proforma and submit this initially to their CTPREC.

1. Checks for Research with Human Participants

Question	Yes/No
1. Will any of the participants be vulnerable? *Note: Vulnerable' people include children and young people, people with learning disabilities, people who may be limited by age or sickness, people researched because of a condition they have, etc. See full definition on ethics website*	No
2. Are drugs, placebos, or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	No
3. Will tissue samples (including blood) be obtained from participants?	No
4. Is pain or more than mild discomfort likely to result from the study?	No
5. Will the study involve prolonged or repetitive testing?	No
6. Is there any reasonable and foreseeable risk of physical or emotional harm to any of the participants? *Note: Harm may be caused by distressing or intrusive interview questions, uncomfortable procedures involving the participant, invasion of privacy, topics relating to highly personal information, topics relating to illegal activity, or topics that are anxiety provoking, etc.*	No
7. Will anyone be taking part without giving their informed consent?	No
8. Is it covert research? *Note: 'Covert research' refers to research that is conducted without the knowledge of participants.*	No
9. Will the research output allow identification of any individual who has not given their express consent to be identified?	No

If you have answered **YES** to any of these questions you are **REQUIRED** to complete and submit a UREC 3 or UREC4). Your supervisor will advise. If you have answered **NO** to all these questions, then proceed with this form (UREC 2).

General Details

Name of student	Nico Caruana
SHU email address	nico.e.caruana@student.shu.ac.uk
Course or qualification (student)	BSc (Hons) Computer Science for Games

Name of supervisor	Peter O'Neill
email address	P.O'Neill@shu.ac.uk
Title of proposed research	A gamified application, which allows the user to safely practice the skills necessary to drive an electric wheelchair.
Proposed start date	1st October 2020
Proposed end date	15th April 2021
Background to the study and scientific rationale for undertaking it.	For many people with mobility issues an electric wheelchair is a necessity. However, learning to drive one can be a daunting prospect. The learning curve can be quite steep depending on the user's confidence in using technology; mistakes and accidents can be potentially painful and/or costly. The Assistive Technology Team at Barnsley Hospital have requested that an application be developed to provide the user with a safe way to practice their wheelchair driving skills. This project aims to build upon that request and explore whether a gaming experience could be considered a valuable tool in the process of learning to drive an electric wheelchair.
Aims & research question(s)	Project aims: • Investigate real-world wheelchair operation, existing wheelchair training solutions and other applications that offer a simulation experience. • Investigate the possibility of implementing an actual wheelchair joystick as the application controller. • Implement the research findings into a realistic driving experience and include gamification. • Improve the application experience using feedback from Assistive Technology Professionals. Research question: Could a gaming experience be considered a valuable tool in the process of learning to drive an electric wheelchair.
Methods to be used for: 1.recruitment of participants, 2.data collection, 3. data analysis.	Participants will be sourced through the university's contacts with the Assistive Technology Department at Barnsley Hospital. Data will be collected in the form of recorded interviews and transcripts of Assistive Technology Professionals (ATP) employed by Barnsley Hospital NHS Foundation Trust. Any opinions provided by a vulnerable member will be relayed by those stated in the above paragraph. The transcriptions will be analysed for recurring trends and other information pertaining to aims of the project.

Outline the nature of the data held, details of anonymisation, storage and disposal procedures as required.	The initial data collected will consist of a video recording where the participant answers a series of questions related to their experience with the project deliverable. After collection, the video files will be stored on an encrypted drive and only accessed by the researcher for the purpose of transcription. Any identifying details will be removed during the transcription process. Once transcription of the video file content has been completed, the original video file will be securely deleted. The transcription document will be stored on an encrypted drive and only accessed by the researcher for the purpose of analysis relating to the project aims. Relevant sections of the anonymised transcriptions may be included in the project report. All transcription documents will be securely deleted upon completion of the project.

3. Research in Organisations

Question	Yes/No
1. Will the research involve working with/within an organisation (e.g. school, business, charity, museum, government department, international agency, etc.)?	Yes
2. If you answered YES to question 1, do you have granted access to conduct the research? *If YES, students please show evidence to your supervisor. PI should retain safely.*	Yes
3. If you answered NO to question 2, is it because: A. you have not yet asked B. you have asked and not yet received an answer C. you have asked and been refused access. *Note: You will only be able to start the research when you have been granted access.*	N/A

4. Research with Products and Artefacts

Question	Yes/No
1. Will the research involve working with copyrighted documents, films, broadcasts, photographs, artworks, designs, products, programmes, databases, networks, processes, existing datasets or secure data?	Yes

2. If you answered YES to question 1, are the materials you intend to use in the public domain? *Notes: 'In the public domain' does not mean the same thing as 'publicly accessible'.* • *Information which is 'in the public domain' is no longer protected by copyright (i.e. copyright has either expired or been waived) and can be used without permission.* • *Information which is 'publicly accessible' (e.g. TV broadcasts, websites, artworks, newspapers) is available for anyone to consult/view. It is still protected by copyright even if there is no copyright notice. In UK law, copyright protection is automatic and does not require a copyright statement, although it is always good practice to provide one. It is necessary to check the terms and conditions of use to find out exactly how the material may be reused etc.* *If you answered YES to question 1, be aware that you may need to consider other ethics codes. For example, when conducting Internet research, consult the code of the Association of Internet Researchers; for educational research, consult the Code of Ethics of the British Educational Research Association.*	No
3. If you answered NO to question 2, do you have explicit permission to use these materials as data? *If YES, please show evidence to your supervisor.*	Yes
4. If you answered NO to question 3, is it because: A. you have not yet asked permission B. you have asked and not yet received and answer C. you have asked and been refused access. *Note You will only be able to start the research when you have been granted permission to use the specified material.*	A/B/C Research proposal was provided by Barnsley Hospital.

Adherence to SHU policy and procedures

Personal statement	
I can confirm that: • I have read the Sheffield Hallam University Research Ethics Policy and Procedures • I agree to abide by its principles.	
Student	
Name: Nico Caruana	Date: 21st October 2020
Signature: Nico Caruana	
Supervisor or other person giving ethical sign-off	
I can confirm that completion of this form has not identified the need for ethical approval by the FREC or an NHS, Social Care or other external REC. The research will not commence until any approvals required under Sections 3 & 4 have been received and any necessary health and safety measures are in place.	

Name: Dr Peter O'Neill	Date: 29th October 2020
Signature:	
Additional Signature if required by course:	
Name:	Date:
Signature:	

Please ensure the following are included with this form if applicable, tick box to indicate:

	Yes	No	N/A
Research proposal if prepared previously	☒	☐	☐
Any recruitment materials (e.g. posters, letters, etc.)	☐	☐	☐
Participant information sheet	☒	☐	☐
Participant consent form	☒	☐	☐
Details of measures to be used (e.g. questionnaires, etc.)	☐	☐	☐
Outline interview schedule / focus group schedule	☐	☐	☐
Debriefing materials	☐	☐	☐
Health and Safety Project Safety Plan for Procedures	☐	☐	☐

Appendix C – Participant Information Form

Participant Information Sheet

A gamified application, which allows the user to safely practice the skills necessary to drive an electric wheelchair.

Legal basis for research for studies.

The University undertakes research as part of its function for the community under its legal status. Data protection allows us to use personal data for research with appropriate safeguards in place under the legal basis of **public tasks that are in the public interest.** A full statement of your rights can be found at https://www.shu.ac.uk/about-this-website/privacy-policy/privacy-notices/privacy-notice-for-research. However, all University research is reviewed to ensure that participants are treated appropriately and their rights respected. This study was approved by UREC with Converis number ER*xxxxxxx*. Further information at https://www.shu.ac.uk/research/ethics-integrity-and-practice

About the study

Please will you take part in a study about the effectiveness of gamification in the process of learning to use a wheelchair.

You have been selected to take part in this study due to your knowledge of and professional experience in the application of assistive technologies.

It is up to you to decide if you want to take part. A copy of the information here is yours to keep, along with the consent form if you do decide to take part. You can still decide to withdraw at any time without giving a reason, or you can decide not to answer a particular question.

You will be required to answer a series of questions relating to your experience with the project deliverable and asked to discuss your opinions on its potential efficacy in learning how to use an electric wheelchair.

These interview sessions will be conducted online via Zoom and will be recorded for the purpose of transcription.

You will need to conduct a minimum of one interview session after using the project deliverable. If you would like to attend more than one session through the project development period, that is also an option.

By taking part in these session(s) you are helping to refine the behaviour of an application which could potentially help many people in the future.

If you wish to discuss your participation at any point, please contact the researcher.

Data Protection

The interview session recording will be stored on a secure encrypted storage drive and only be viewed by the researcher for the purpose of transcription. During the transcription process all personally identifiable information will be removed. Once the transcription is completed, the original video recording will be securely deleted. Transcription files will be stored on a secure encrypted storage drive and only be accessed by the researcher for the purpose of analysis relating to the project aims. Relevant sections of the anonymised transcriptions may be included in the project report.

When the study is over, the researcher will be responsible for all collected information. The only person with access to the information will be the researcher. On conclusion of the study, the researcher will ensure all raw data will be securely deleted from the encrypted storage drive.

After the study

Findings from the research will be used to write a final project report and conduct a presentation of the findings to a university marking panel. If the research is deemed to be of sufficient quality, the report may be selected to be published as a piece of work undertaken at Sheffield Hallam University.

The study is expected to complete by the 15th April 2021.

To find out the results of the study, please contact the researcher or the university.

If you would like the opportunity to ask any further questions or seek clarification, please feel free to contact the researcher or the university.

Details of who to contact if you have any concerns or if adverse effects occur after the study are given below.

Contact Details

Researcher/ Research Team Details:

Nico Caruana – nico.e.caruana@student.shu.ac.uk / nicocaruana@gmail.com

University Contact Details:

You should contact the Data Protection Officer if:	You should contact the Head of Research Ethics (Professor Ann Macaskill) if:
• you have a query about how your data is used by the University • you would like to report a data security breach (e.g. if you think your personal data has been lost or disclosed inappropriately) • you would like to complain about how the University has used your personal data DPO@shu.ac.uk	• you have concerns with how the research was undertaken or how you were treated a.macaskill@shu.ac.uk
Postal address: Sheffield Hallam University, Howard Street, Sheffield S1 1WBT Telephone: 0114 225 5555	

Appendix D – Participant Consent Form

Sheffield Hallam University

PARTICIPANT CONSENT FORM

TITLE OF RESEARCH STUDY:

A gamified application, which allows the user to safely practice the skills necessary to drive an electric wheelchair.

Please answer the following questions by ticking the response that applies

	YES	NO
1. I have read the Information Sheet for this study and have had details of the study explained to me.	☐	☐
2. My questions about the study have been answered to my satisfaction and I understand that I may ask further questions at any point.	☐	☐
3. I understand that I am free to withdraw from the study within the time limits outlined in the Information Sheet, without giving a reason for my withdrawal or to decline to answer any particular questions in the study without any consequences to my future treatment by the researcher.	☐	☐
4. I agree to provide information to the researchers under the conditions of confidentiality set out in the Information Sheet.	☐	☐
5. I wish to participate in the study under the conditions set out in the Information Sheet.	☐	☐
6. I consent to the information collected for the purposes of this research study, once anonymised (so that I cannot be identified), to be used for any other research purposes.	☐	☐

Participant's Signature: ____ **Date:** ___________

Participant's Name (Printed): ___________________________________

Contact details: ____

____

Researcher's Name (Printed): ___________________________________

Researcher's Signature: ______________________________________

Researcher's contact details:
(Name, address, contact number of investigator)

Please keep your copy of the consent form and the information sheet together.

Participant Consent Form 1 V1

Appendix E – Prototype demonstration feedback

13th October 2020 – Email Correspondence

Hi Nico

Good to meet you today. Just to summarise what we discussed.

Discussed purpose of app

You have had a look around the literature and are aware of various virtual reality type wheelchair training systems systems that have been used.

I suggested that we were looking for something that might be more accessible to the general user and available to use at home and not just when actually training and using the wheelchair itself

If it could include general controls but if possible some of the sort of finer controls or scenarios someone might encounter -e.g. kerbs, unexpected changes in ground surface that might affect handling, obstacles in the path (static and moving, unexpected hazards.)

I wondered if there would be scope to have levels or scenarios of different levels of challenge?

Re: type of wheelchair – I 've spoken to our wheelchair expert, [ATP2] and he says the Quickie Salsa M2 is a very common wheelchair but is due to be discontinued soon although there will still be lots out there.

[ATP2] says that we actually have the planned replacement for this – the Quickie q400 - in our workshop ([ATP2] uses these for testing the safety of mounting and the integration of controls) and if you wanted to come and have a look at it Mondays would be a good day. They also have an Invacare Aviva. I think the main difference is that the Quickie is mid wheel drive and the Invacare is rear wheel drive. I think this does make a difference to handling but I wonder if the game could be less subtle than this would make a difference to?

Access -   it looked good on what you showed me as a user could use a joystick and if I understood right the Xbox adaptive controller to use switches. I'm not sure whether/ how this would work on other platforms but would be good if it could. iOS has switch access as does android so great if this is possible but can also use with joystick (as long as after iOS 13) on these.

Target audience – this could be aimed at different target audiences – children, and adults with acquired disabilities that meant they started to need to use a powered wheelchair so might not want to be too child orientated in interface or maybe have different options within the game for environment/ rewards.

It would be great if you can send me a link to try it out. I'll let you know if it works. If it's ok we can also send it to [SUR], our team's service user representative and he can have a go and give feedback.

Let me know if you are interested in coming to the workshop to look at the wheelchairs and I'll speak to [ATP2].

Thanks for your work so far!

Best wishes

[ATP1]

Appendix F – First playable review feedback

21st October 2020 – Email Correspondence

Hi Nico

Thanks for that. The link seems to work fine and the principles are there and I can control with the mouse (and so a plug in joystick and likely switches with switch driver) Not sure it fair to comment too much yet as I'm sure you will be working on the things I would mention, like the consequences for goings over big ramps or half on half off small kerbs. I did also manage to fall into some sort of infinite void by going off the edge but again I'm sure the edge is in the pipeline! Drop me a line if you do make significant changes and I will look again and I can share link with the team.

I think that data logging was suggested so anyone could see progress and use – does that make sense? So it would be useful but I don't think it is the priority.

I guess the Q400M would be the replacement for salsa M2 as it's mid wheel drive and other seem to be rear or front wheel drive. I can have a look at which one we have when I'm in the office next as I think the mech chaps will have got the one that is expected to be most common.

Best wishes

[ATP1]

Appendix G – Second playable review feedback

21st February 2021 – Email Correspondence

Hi Nico

I've had a bit more of a look at the app.

I think it does seem to give an experience of the care needed to navigate safely with a wheelchair (I am a bad wheelchair driver, but I think I could improve with this getting used to how you need to move a joystick to make small movement to get the wheelchair straightened up for example)

I found I could use ok with a mouse and the on screen joystick. I liked being able to go back to a check point (when I fell off for example) but I did get quite disorientated at times as to where I was and ended up going the wrong way. This might be easier for someone who is a gamer and is used to this sort of thing but it's hard if you have limited experience of navigating a virtual environment.

I tried it with click lock so I didn't have to keep holding the mouse button down which could be hard for someone with limited dexterity so that might be worth putting in any instructions.

When I completed a level it seemed to get stuck and I couldn't get out of the completion screen. I did once by accident but I'm not sure what I did and I couldn't replicate it. I just reopened it in a new tab to do another activity.

The onscreen button to exit is much better if you change your mind before finishing.

Could there be a record of the user's completion times so someone could see progress?

I tried it with 2 joysticks this one https://www.pretorianuk.com/n-abler-joystick which has buttons on it to press for clicks and this one where you plug in a switch to click https://www.pretorianuk.com/ultra-joystick but unfortunately, I could only get them to work in mouse mode, so it was a bit tricky. Not sure if it would work if they went through an adaptive controller? Do you know any joysticks that would work out of the box? Can you plug a game controller into a computer and would that work?

I just can't remember what [SUR] uses for his tablet - I think it might actually be a separate joystick like one of these. I let him know what you said so we'll see what he says.

I'll let you know if I think of anything else.

Best wishes, [ATP1]

Appendix H – Third playable review feedback

2nd March 2021 – Email Correspondence

Hi Nico

Thanks for coming today.

I had given you some feedback before and you've added some fixes and changes so that is great.

You've added the on screen escape button to exit play screen.

You've fixed the getting stuck on level completed screen issue.

You responded to my comment about me getting disorientated when going back to a check point by adding a feature where camera pans out to show where you are and the direction you are pointing in.

I've now tried this and definitely found it helpful.

Here is a summary of today feedback.

[SUR] feedback:

- "I loved the app"
- "This is amazing for disabled children or everyone who wants to try an electric wheelchair"
- "I can see it as a game"
- [SUR] asked if it could have a way to make the controller move faster or slower like a wheelchair controller can be set to go faster or slower.
- [SUR] suggested sounds would improve playability.
- [SUR] suggested symbols on the buttons in start menu (and on any menu) so someone who is non literate could choose which course they want or start it going.
- [SUR] asked about a possible idea for the future where it could be used in a VR simulator and you said it might be possible to transfer this program to that platform
- Possible competitive element with leaderboard for times for different players.
- [SUR] also suggested the idea of Wheelchair Football with this game for a future idea!

[ATP1] feedback:

- I enjoyed playing the game and trying to improve my performance in getting round the courses and I thought it did simulate the type of control you would need for using a wheelchair.
- Could there be a scoreboard so a player can see their progress and if times/ accuracy improving? (?linked to leader board?)
- Could there be some moving obstacles for the player to deal with? You said these are in the pipeline.
- Help page – simple instructions for use e.g. how to use on screen controller, different methods of control (e.g. keyboard, mouse with click and drag or using click lock, games controller)

- Orientation (also from [SUR]'s partner) -Could there be colours or arrows to help with orientation

I forgot to ask you today but does it have the potential to be used on a phone or tablet with a mouse or joystick plugged in?

Great to see how the app is progressing. Let me know if there are any updates you'd like us to look at.

Best wishes

[ATP1]

Appendix I – Fourth playable review feedback

31st March – Email Correspondence

Hi Nico

Thanks for coming and thank you for all you hard work on this.

Quick summary of yesterday's meeting (although I'm sure you wrote anything down you needed!)

From [SUR]:

- The joystick is better now
- Likes the start screen and the button that takes you to the start
- Would like to see a speed control
- Give it 9 out of 10 !

From [ATP1]:

- Liked all the developments in progress in response to feedback
- Leader board potential
- Visual display – feels a lot easier to interact with
- Help button (or potential for help)
- Checkpoints – work well in orientating me when get stuck
- Moving obstacles
- Seemed to work well for me on my phone – also just using finger was closer to using a joystick for me than using my mouse (although could use joystick on PC with click lock)
- Sound on collecting tokens

I agree with you that music could be distraction – maybe you could have option to turn it on or off. Could add it almost as an extra level of difficulty i.e. playing it with an extra distraction as would sometimes drive wheelchair in noisy distracting environments. Then again some people find music helps them concentrate – music design is a whole other area isn't it!

It did just occur to me as well whether the manual bit is as relevant as someone using a manual would be propelling a wheelchair with their arms rather than using a joystick

I find it quite playable, although it is hard for me. I had to concentrate but I felt that that imitates how I would have to be using a wheelchair as I'm getting used to those controls.

I probably should have directed you to these before but if you are interested in developing it further it could be worth getting in touch with a local NHS wheelchair services and getting their opinion. I think the current Covid situation has made it bit more difficult for you too as otherwise you could have come and tried our wheelchair (our Tech team keep one for testing mounting even though we don't issue chairs)

It sounds like [SUR] is very interested in pitting himself against some more amateurs like me!

I'll send you a formal feedback sheet which I send to [Project Supervisor] too – hopefully by next week but hopefully you've got what you need for your assignment.

Get in touch if any questions

Best wishes

[ATP1]

Appendix J – Feedback Summary Form

Barnsley Hospital Quality in Care

Barnsley Hospital NHS
NHS Foundation Trust

Wheelchair Driving Practice Game App Feedback

App Author: [redacted] Sheffield Hallam University

App Reviewers: [redacted] Barnsley Assistive Technology Team

[redacted] Barnsley Assistive Technology Team

Realisation of concept

The app meets the specification of the project to design a game which allows the user to practice some of the skills required for driving a wheelchair, including steering, navigating turns and slopes and avoiding moving obstacles.

It is accessible on a PC or the android platform and can be used via a touch screen or with a connected mouse or joystick, which is helpful as this makes it accessible to a range of users.

The game includes an on screen controller, representing the wheelchair joystick. This does gives the experience of using a real joystick, including getting used to how you need to move a joystick to make the chair move in the direction wanted.

There a number of different courses to practice navigating different environments and moving obstacles and it includes a timer so the user can see how fast they are able to navigate a course and monitor if they progress.

You've made changes to the app in response to feedback and created a usable app with lots of potential for further development.

Usability

You regularly sought feedback and improved the usability of the game for the player over the course of the development in response to feedback including:

- Provided more visually accessible ways to enter and exit the game, and choose courses. It is easy to see what you need to do to get to a level, how to go back to a checkpoint and how to exit the level.

  You're planning to improved this further with visual aid to what the different levels are as well as a description
- Improved orientation by including the ability to return to checkpoints, with an animated aerial view so the player can see what position they were in before they returned to the checkpoint and where they are in relation to the whole course and then where they are before they start again.
- Included moving obstacles to navigate
- Added the potential for a scoreboard
- Added the potential for a help section
- Added sound on collecting tokens. We felt sound would be good, within the game, but you are still thinking about this and wanted consider the potential for this being a distraction.

It is enjoyable and absorbing to play.

[redacted] has very limited experience of driving a wheelchair and felt it was challenging but encouraged her to try harder to complete the courses faster and with fewer bumps and falls   She thought that it was similar to her experiences in driving a wheelchair as it replicated how careful it is necessary to be to make sure the controller is in the right position to go in the direction wanted and not to rush this.[redacted] is an experienced wheelchair driver and he said he loved it, that he thought it would be good for people to get the experience of trying an electric wheelchair and that he could see it as a good game as well as a good way to practise.

Future developments

Ideas for future development are:

Include in help section simple instructions for use e.g. how to use on screen controller, different methods of control (e.g. keyboard, mouse with click and drag or using click lock)

[redacted] has suggested that it would be good to be able to vary the speed of the wheelchair goes in response to the controller.

Finish the leader board for individuals to track progress but also for multiple users to compete.

Potential to transfer to a virtual reality platform.

Switch Access – some wheelchair users need use switches to control the wheelchair so it would be an option to use switches to control the game. It would also make it more accessible to general users.

https://www.oneswitch.org.uk/index.php has useful information about using switches for games.

[redacted] also suggested the idea of Wheelchair Football with this game for a future idea!

It might be helpful to also contact a wheelchair service for further feedback and advice.

[redacted]

Assistive Technology Clinical Specialist Occupational Therapist

Assistive Technology Team, Barnsley

04/04/21

Barnsley Hospital, Gawber Road, Barnsley. S75 2EP
Web: www.barnsleyhospital.nhs.uk/at/ - Email: Barnsley.AT@nhs.net - Phone: 01226 432159

Appendix K – Game Design Document

Wheelchair Driving Practice

Game Overview

Vision statement

The game invites the player to experience what it's like to drive an electric wheelchair in a variety of different situations, get familiar with the controls and prepare for the use of one in the real world.

Genre

This game is a semi-realistic simulation game.

Overall aim of the game

The aim of the game is for the player to complete a series of driving challenges within a time allocation, building up their confidence of driving an electric wheelchair.

Audience

The game is intended to be played by people who will be using an electric wheelchair in real life. It is more of a learning tool than a commercial venture, and is expected to be provided at no cost.

Target platform

The game will be released on Android and IOS devices.

Key Features

There will be a selection of 15 levels of increasing difficulty point A to B style challenges to the player to improve their driving skills.
There will also be a more free form “Crazy Taxi” style mode, for more general driving practice and enjoyment.
The player will be able to select from multiple different wheelchair styles, to get a feel for how the different models control in the real world.
The player will be able to optionally collect a currency during levels, which can be used to obtain cosmetic items to customise their wheelchairs.

Unique characteristics

The game is primarily intended as a learning tool that can be used by an unsupervised player in their own home, and as such focuses heavily on the driving accuracy of the wheelchairs. Other wheelchair simulation gaming products on the market are mostly whimsical offerings, which offer little in the way of transferable real world experience, and are mainly used to highlight wheelchair users in general. The existing products which do fulfil the simulation aspect are mainly virtual reality experiences, and as such require prohibitively expensive hardware and supervision during their use.

Artistic style

The game will use simplified characters to ensure that any accidents are not likely to cause any trauma to the player.

The Game World

The skill based levels will be very restricted in the areas that the player will be allowed to explore. Ensuring that focus is solely on performing the required movements to complete each stage.
The “crazy taxi” mode will be more open world, and allow the player greater freedom. The zone itself will be a small city section, with ramps to climb, roads to traverse, and moving objects to avoid.

Specific player objectives

The goal of the skill based levels will be to complete them within the quickest possible time.
There will also be optional collectable items which can be used as a currency to purchase cosmetic upgrades.

Game Specifics (Details)

Detailed features of the game world

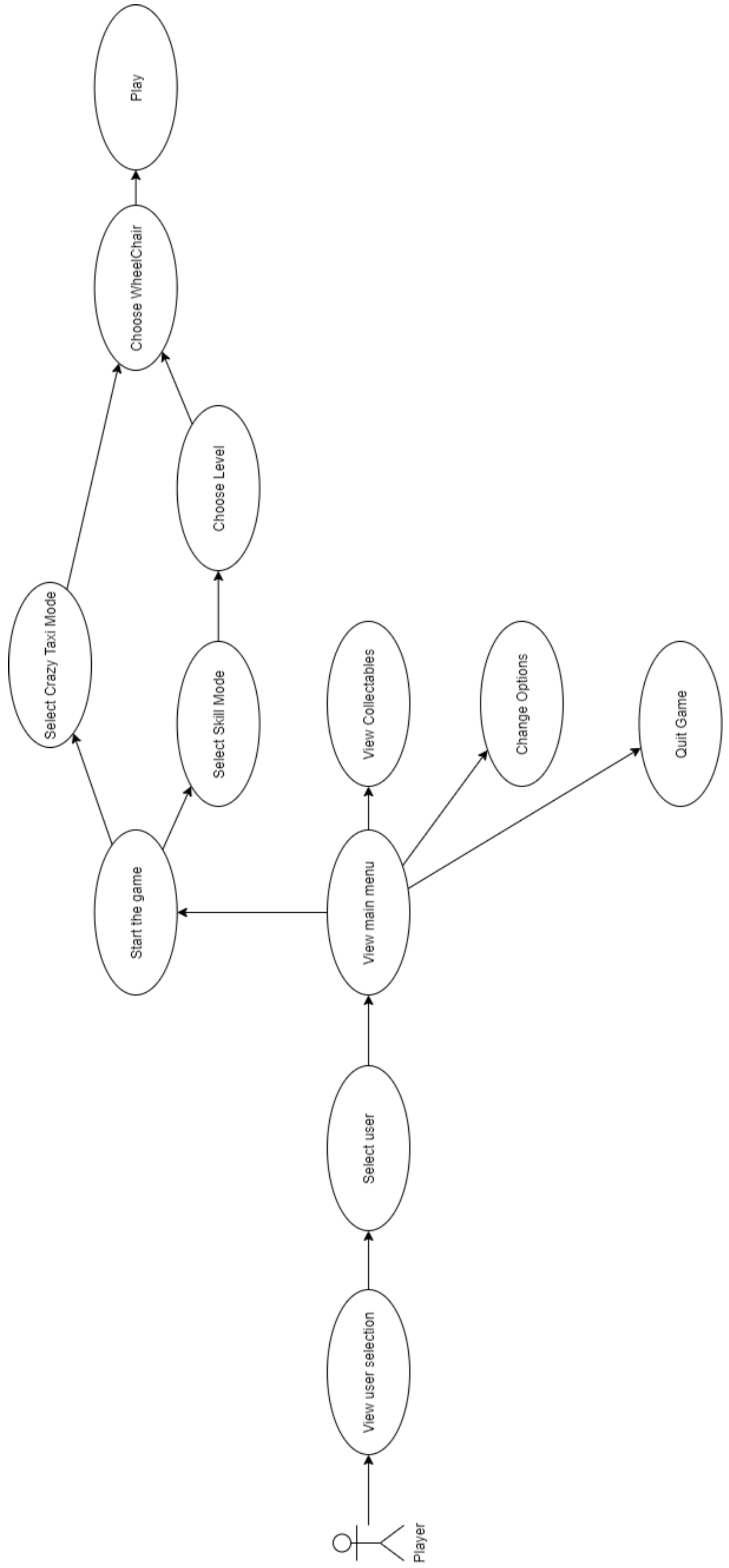
Checkpoints will be used to allow the player to return to a previously visited location in the event of a crash or fall.
Platforms and ramps will be used to create transitions between vertical levels, sizes in accordance with accepted legal standards.

User Interface Design

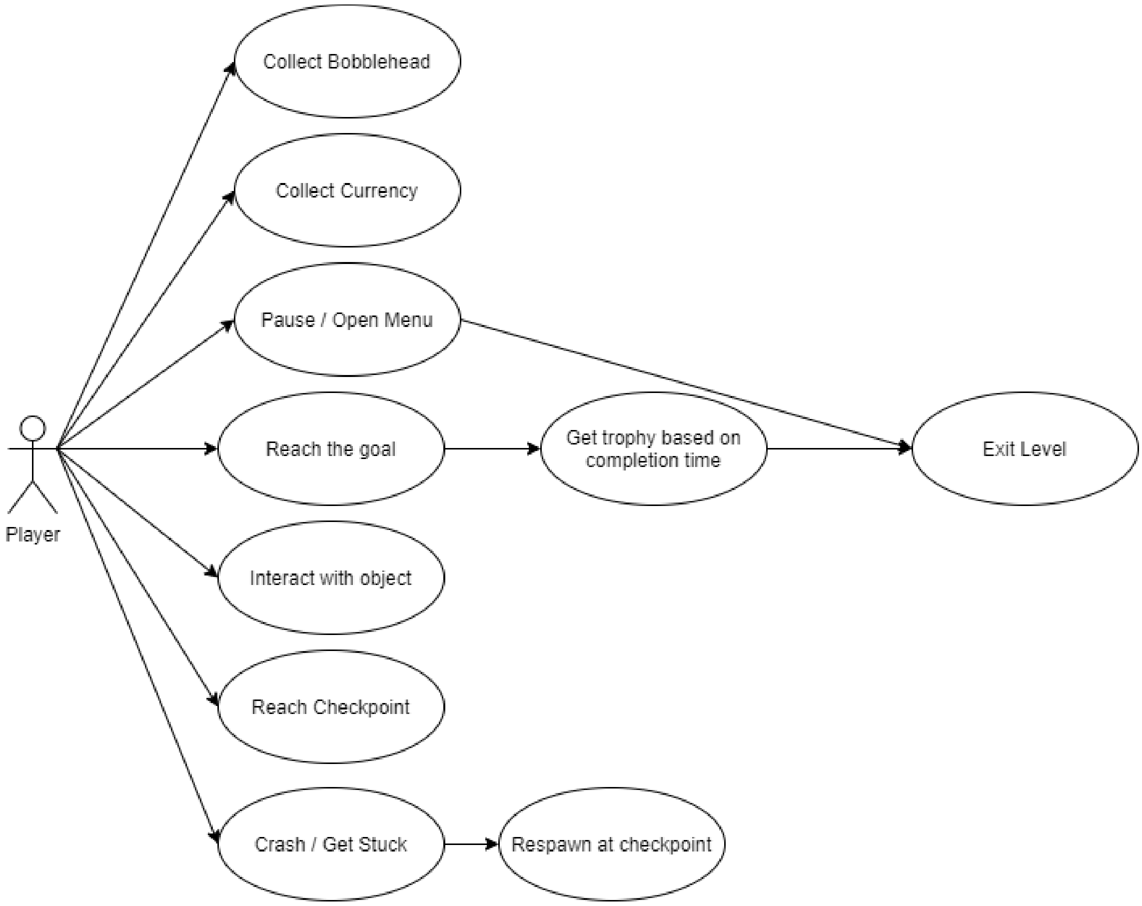
Control method(s)

An on-screen joystick will be used to provide a means of controlling the chair, but the main aim is to use a real wheelchair joystick.

Appendix L – Menu Navigation Use Case Diagram



Appendix M – Skill Mode Gameplay Use Case Diagram



Appendix N – Technical Research

A comprehensive historic review of the functionality, operation, and development of electric powered wheelchairs(Stout, 1979). Although quite dated in terms of technology, the concepts are still relevant to the present day and provide a good all-round foundation to build upon.

A university project which involved the construction of a DIY Electric Powered Wheelchair was also examined (jtaggard, 2016). This proved extremely useful, as being unable to access a real chair, it gave some idea of the dimensions involved, issues faced, and an insight into the implementation details.

Discovered through an Arduino blog post (ARDUINO Team, 2017), a project where a team of students modified an existing wheelchair to be electrically powered and controlled was researched. This provided a thorough description of the engineering process and an example of programming the joystick input handling at a low level, factoring in dead zone and input outliers (Dascalu, 2017).

A look at some of the early research into wheelchair simulation, provided insight into some of the fundamental concepts needed to provide a realistic representation. There was also a good description of the relationship between joystick control and motor speeds (Niniss & Nadif, 2000).

This study features a full description of the creation process of a virtual reality wheelchair simulator that filters out rogue inputs from users suffering with Parkinson’s disease, including much of the maths behind the physics. Lots of information on the manual creation of an input converter like the Freedom wing adapter (Sergeeva, 2017).

As technology has advanced, far more bespoke solutions are becoming apparent, such as this case, which goes one step further and uses robotics to create a mixed reality wheelchair simulation to aid research into Parkinson’s tremor mitigation. (Meyer & Sergeeva, 2020).