Improving the Self-Balancing Wheelchair

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Final Year Project

10 Page Summary

THE GLASGOW SCHOOL OF ART

University of Glasgow

GU68 ENGINEERS TRUST

Project Background

Self-Balancing Wheelchairs

Self-balancing wheelchairs comprise a seat and stabiliser mechanism fitted to the top of a Segway. This allows them to be controlled in the same way as the Segway, i.e., leaning forwards and backwards controls forward and backward motion, and turning is controlled by the pivoting of a central steering column. This provides the user with more intuitive and involved motion control than standard electric wheelchairs. It also enables greater agility and freedom as the devices can turn on the spot and cover a multitude of terrains. Despite these benefits, two major problem areas were discovered within the product. These are highlighted on the diagram below:

‘Nino Robotics’ Self-Balancing Wheelchair - image from [1]

This document summarises the design of solutions to both these problems.

Although there are several brands of self-balancing wheelchair, solutions were devised specifically for the ‘Nino’, the chair displayed above, as this is the brand common to the users consulted with during the project. Nevertheless, the issues uncovered are common to most existing products. Therefore, with some alteration, the conceived solutions would be compatible with other self-balancing wheelchairs.

Insights

These problem areas were highlighted during discussions with two self-balancing wheelchair users as well as the founder of ‘All Access Mobility’, one of the UK’s largest self-balancing wheelchair distributors.

Extensive codesign and user testing was done with one of these users throughout the project, enabling valuable insights to be continually collected.

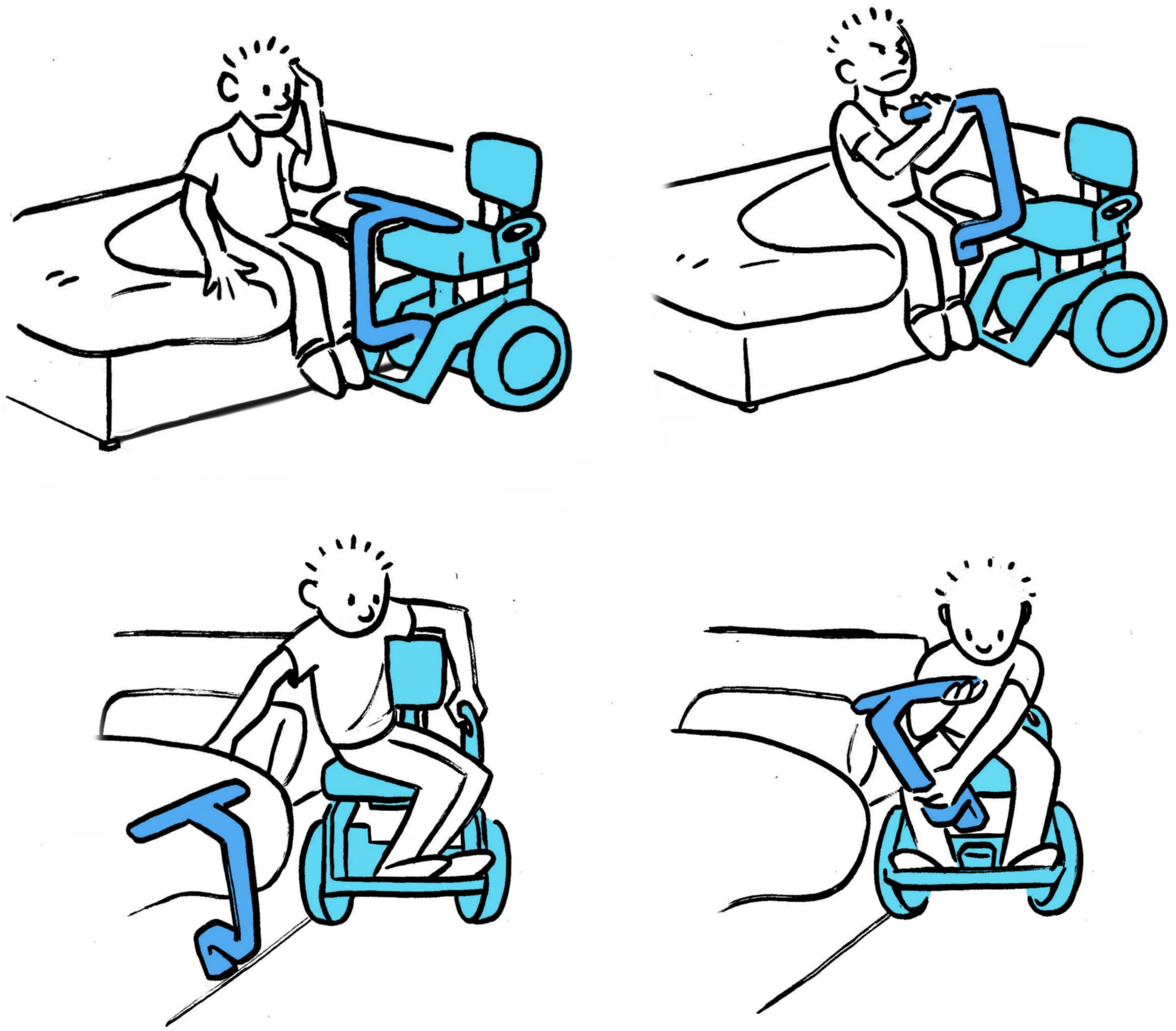
Various Technical experts were also consulted as the project progressed, in order to validate and inspire engineering solutions.

All Access Mobility Logo - image from [2]

The Problems

The current steering column must be removed every time a user gets on or off their wheelchair, this is known as transferring and is usually done multiple times a day. Removal is necessary because the column obstructs the user's legs and so navigating around it while transferring is impractical. Several issues stem from this process:

1. Repeatedly lifting and orientating the large heavy column is tiresome for any user and becomes especially difficult for those with muscle degeneration.



2. Once on the chair, the user must reach to wherever they left the column, before orientating it back into the connection point. This requires uncomfortable twisting motions and is difficult to do as the location of the insert point is far down beneath the seat and hard to see.

3. Finally, the column is impractical for use in many indoor scenarios as it creates an obstacle between the user and the confined environment they want to interact with, particularly as it is too high to fit beneath countertops.

Edited version of image from [3]

The Solution

Edited version of image from [3]

An effective solution to these problems is to split the steering column into two parts. The bottom ‘stem’ section is out the way of users legs and so does not have to be removed when they get on or off the chair - therefore minimising the size and weight of the part to be lifted by the user. Only the upper handlebar now has to be moved. These new handlebars will be manufactured from a light weight composite material to further reduce the user lifting strength requirements.

There are two handlebar options, one for outdoor steering, and one for indoor. The outdoor handlebar has a flat top to allow for forearm steering if the users’ hands get tired on long journeys; something that is quite common for those with Motor Neurone Disease or Multiple Sclerosis. The indoor handle is far smaller in height allowing it to be used for indoor steering beneath countertops.

These handles are stored on either side of the chair in a location where they are easy to reach, yet create no additional obstruction. This means that there is no longer a need for excessive reaching as was necessary when handlebars could not be stored on the chair itself. Finally, because the connection point is now at the top of the fixed stem section, handle re-insertion is simpler to achieve as the connection point has been brought closer to the user and is easier to see.

Key Features

Holster Design & Manufacture

A tapered entrance to the handlebar holster helps to guide the users hand when inserting the handles. The part will be 3D printed from 'eSUN ELASTIC' filament at 100% infill. The viability of this material and process were determined through testing. As the material behaves like rubber, it provides vibrational dampening which prevents the handles from rattling.

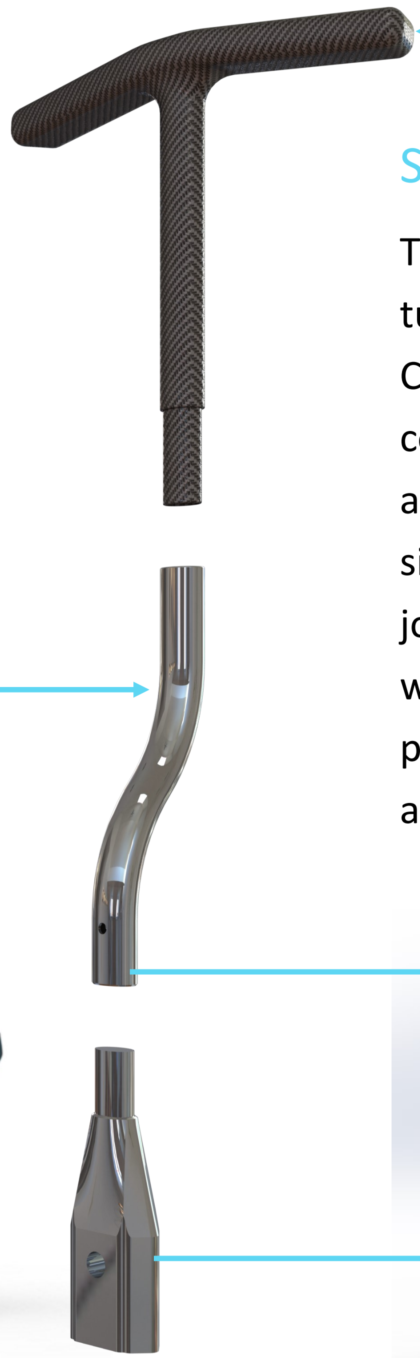
Holster placement

Iterative testing of handle and holster placements was done using a 1:1 model in order to find the optimum.

Handlebar Ergonomics

As previously mentioned, the outdoor handlebar features a flat top to allow forearm steering. The handles themselves are also connected at a slight angle to minimise strain on users wrists. These features were perfected through foam modelling codesign sessions.

Edited version of image from [3]

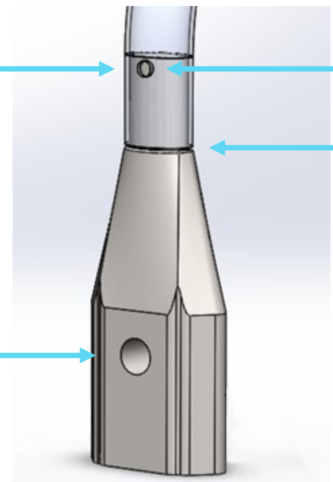


Handlebar Manufacture

The handlebars will be made from a light weight carbon fibre epoxy composite. This was chosen after an extensive material selection process. The specific design of this composite was determined through 'Classical Laminate Theory' calculations, as well as simulated and analytical stress analyses. For optimum results the handle would be produced following a bladder forming procedure.

Stem Manufacture

The stem comprises a section of bent elliptical tubing welded to a solid CNC machined part. This CNC'd part is what slots into the Segway's connection point. Both parts are made from 6063 aluminium alloy, a material deemed suitable after simulated and analytical stress analysis. A strong joint has been achieved by incorporating a plug within the CNC'd part. The tubing slides over this plug, allowing for the parts to be welded together at two separate points.



The Process

A large part of the design process for this product involved physical prototyping and user testing. The steering column redesign went through many iterations, as it gradually became more refined, based on testing results and user feedback. Where possible, testing was done using a self balancing wheelchair with a target end user. However, when this wasn't possible (due to lockdown restrictions or other COVID-19 related issues) testing was instead done with other users using 1:1 models to simulate an accurate experience.

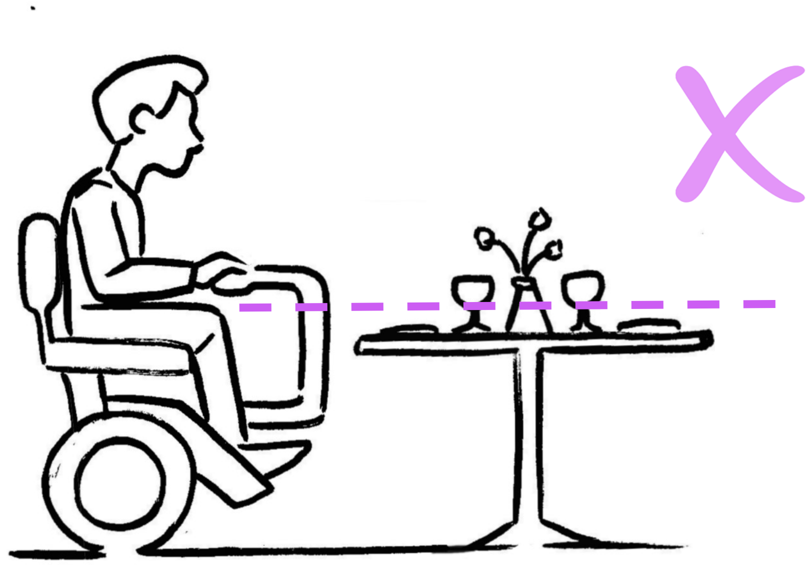
The Problem

Wheelchair users get on and off their chair multiple times on any given day. Transferring to or from a surface that is not level with the wheelchair's seat is extremely difficult as it means the user must physically raise or lower themselves.

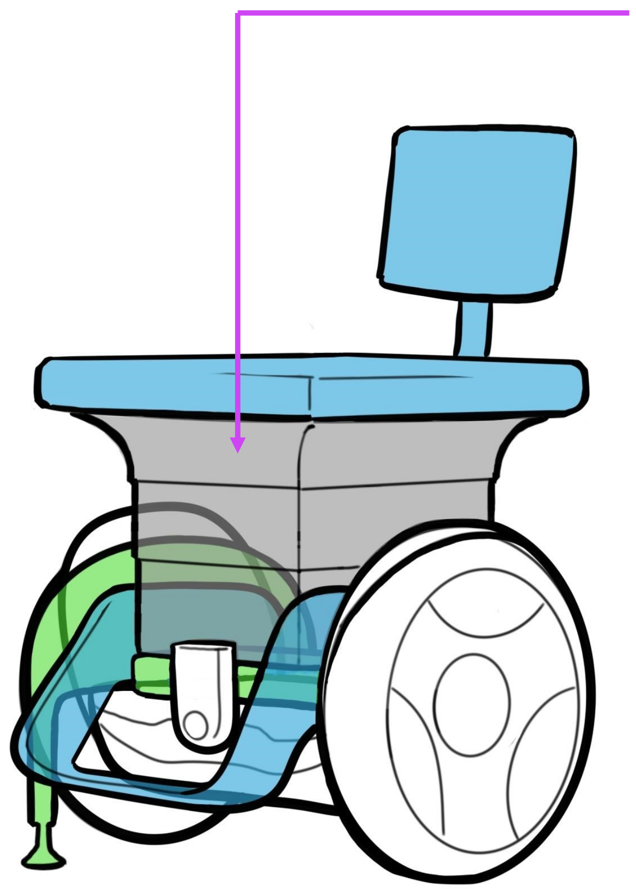
To solve this issue, it is best to incorporate some form of height adjustment mechanism within the chair. Most self-balancing wheelchair seats sit at a height of 60cm which is beneficial when it comes to user's independence and confidence, as they can reach higher up as well as be closer to the eye level of those standing. A height reduction of 15cm is then sufficient to bring the seat level down to that of most standard dining chairs – thus improving most transfer situations.

Image from [4]

Image from [1]



For example, when visiting a restaurant, users are forced to transfer in order to sit at a table, something which attracts a lot of unwanted attention.



The height adjustment solution must also be able to fit within the narrow volume available within a Segway's wheelbase.

A fundamental change such as this would be applied at the design phase of the next generation of self-balancing wheelchairs, at which point the steering method should also be redesigned. The steering column developed in this project is intended as a quick fix to be retro fitted to existing chairs. When starting from scratch it would be better to incorporate some form of joystick or motion control – as this removes the steering column issues and is more suited to a variable seat height user.

The Solution | User Centred Features

The solution found for the seat height problem is to integrate a narrow motorised scissor lift within the wheelchair. The lift is controlled via easily accessible 'up' and 'down' buttons, allowing the user to adjust their seat to the heights of most common transfer surfaces - around 45cm. The lift has a 15cm range of motion meaning that the user can still ride around at a seat height of 60cm.

Button Placement

There are two sets of control buttons, one on either side of the lift. Through user testing this was found to be desirable as it allows the lift to be operated from a number of transfer positions.

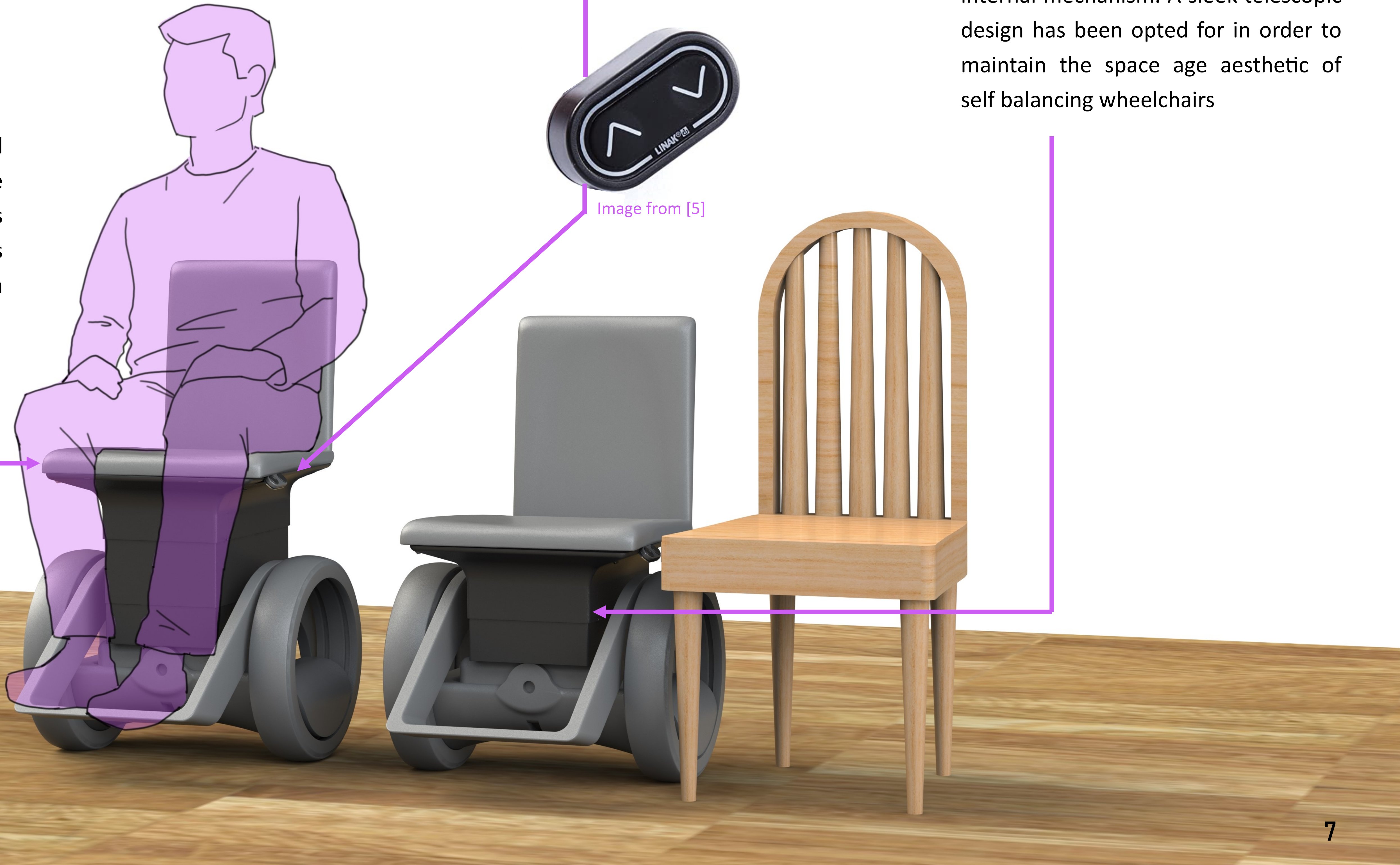
Button Selection

The chosen buttons have different form factors, allowing for tactile distinction between the two. This means the user can operate the lift without having to look down.

Image from [5]

Lift Cover Design

After carrying out a risk assessment, and interviewing an expert in the field, it was determined that a cover over the lift was essential to protect both the users fingers, as well as the internal mechanism. A sleek telescopic design has been opted for in order to maintain the space age aesthetic of self balancing wheelchairs



The Solution | Technical Features

Standard Components

'DURHANDS' motorcycle scissor lift stand (shown below) is an existing product that provides a near perfect fit into the volume available. With some adjustment, and the addition of a few custom components, the lift is suitable to be motorised and integrated onto a self-balancing wheelchair. This means that many components within the final design can be directly transplanted from a cheap existing product - resulting in an economical solution.

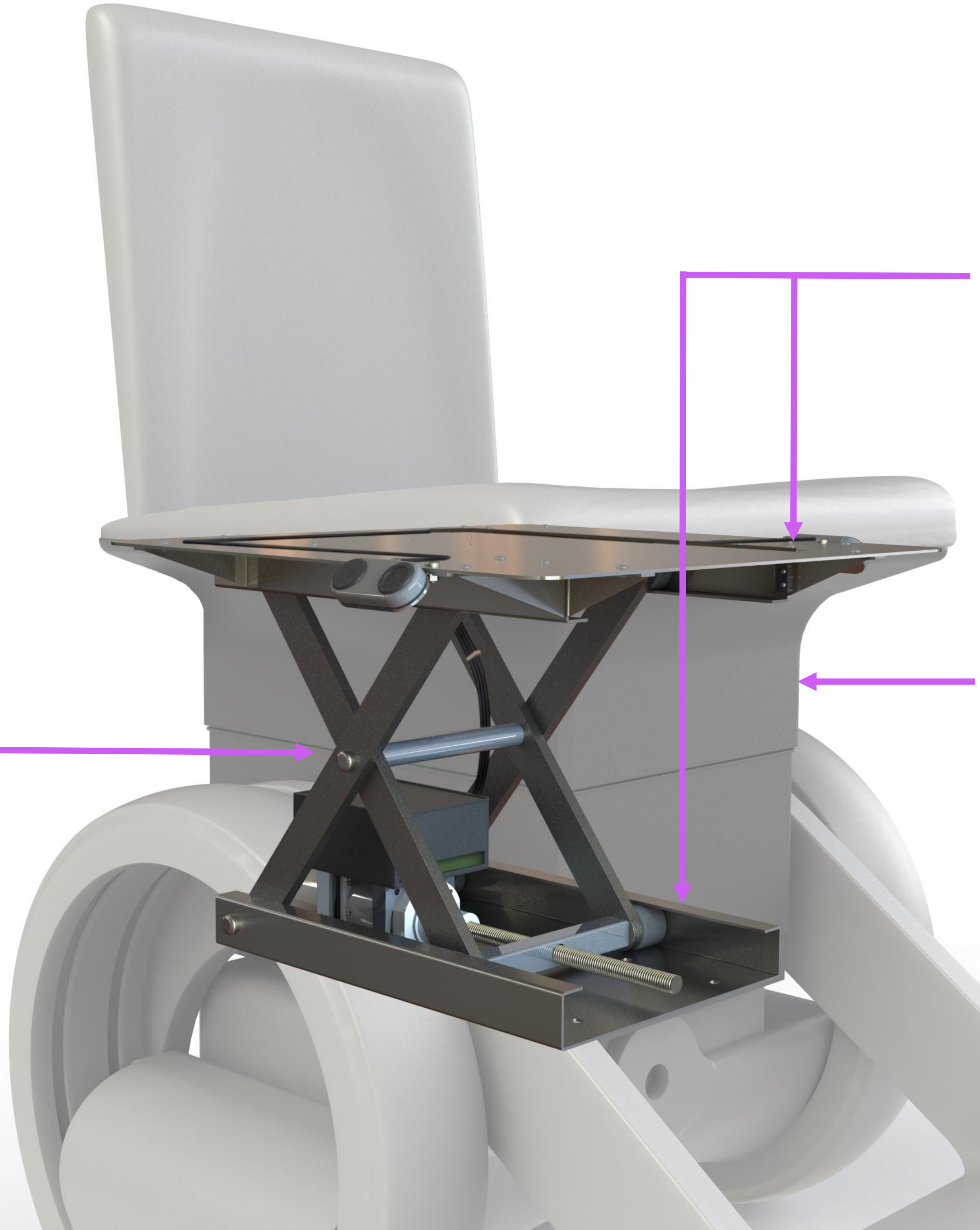
This also applies to the chosen control system components which, except for the electronic control unit, are all standardised.

Image from [6]

Motor Selection

Through analytical and experimental mechanism analysis, a motor and gearbox configuration capable of driving the scissor lift was chosen. This required dynamic force modelling, lead screw calculations and Newton balance experimentation.

A brushless DC type motor was selected as it will operate at very low noise, resulting in less attention being drawn to the user if using the product in public spaces.



Custom Components

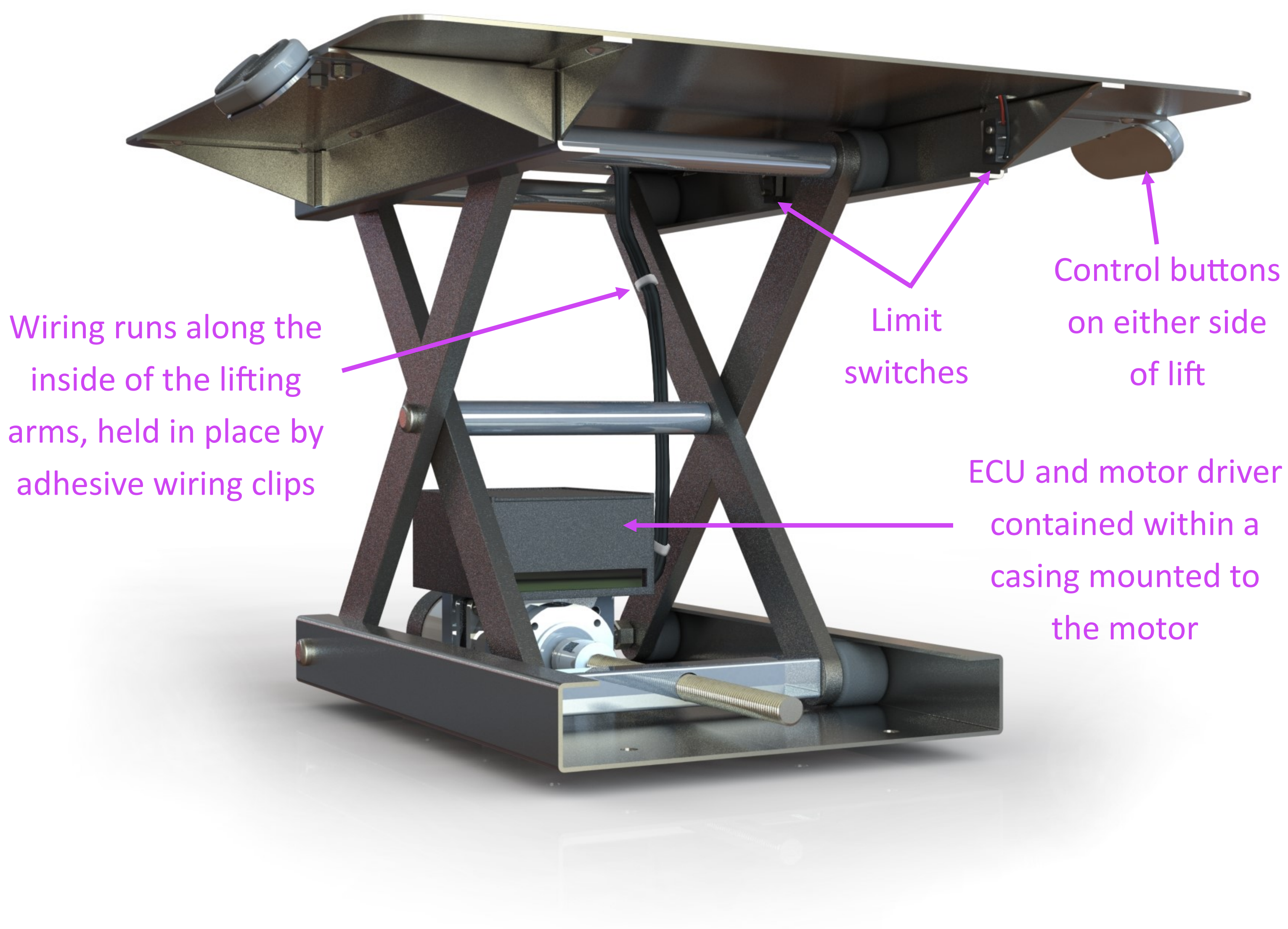
There are only a few custom components required for this product. The upper and lower plates, the telescopic sheath, and two aluminium CNC machined motor brackets.

- The upper and lower plating is formed from several bent steel sheet metal sections riveted together. This is an inexpensive production process requiring no time consuming welding during assembly. The required form and thickness of this plating was identified through 'Finite Element Analysis' simulations.
- The cover components are designed to be vacuum formed from HIP, an economical manufacturing process chosen because of its low tooling costs. Draw ratio calculations were performed to identify optimum moulding orientations and required sheet gauge.

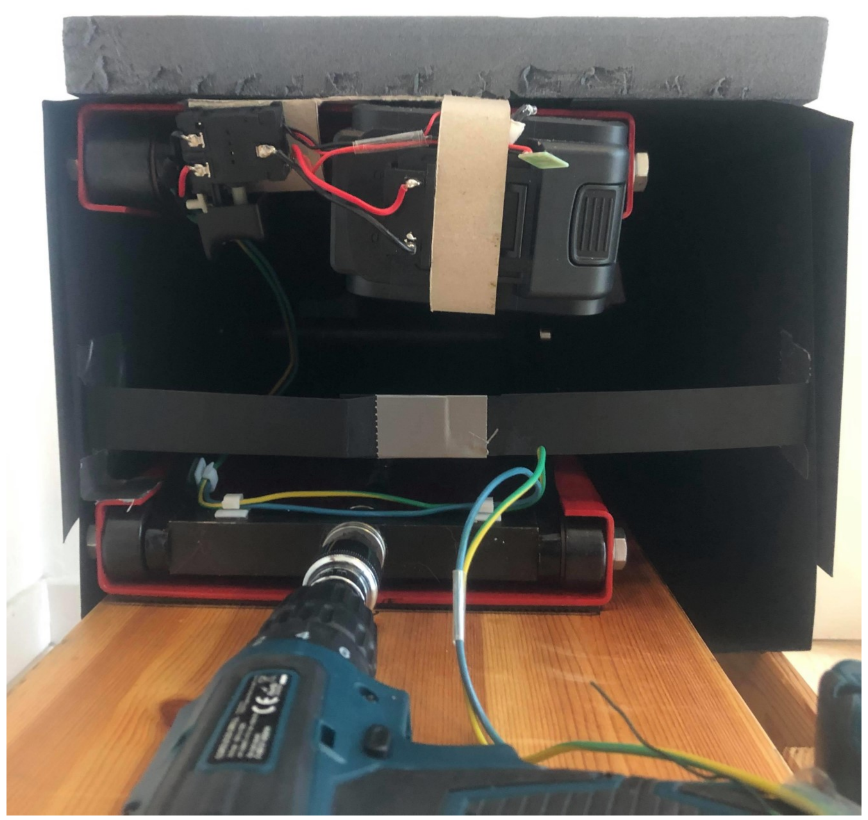
How it Works

As mentioned previously, lift motion is controlled by up and down buttons on either side of the chair. Limit switches are screwed into one of the upper runners and are triggered when compressed by the lifting arms. Lift motion is not permitted when either limit switch is pressed. This restricts the range of movement of the lift, constraining the lifting arms between safe angles. If no limit switch is triggered, the lift is free to move up and down following the specified user input.

Signals from these buttons and switches pass through the onboard electronic control unit (ECU) which controls how the motor responds. A motor driver acts as an interface between these components. The motor itself rotates a power screw, the rotational direction of which either moves the lifting arms closer together or further apart, raising or lowering the lift.



The Process



Early on in the project a functional motorised scissor lift prototype was created, capable of replicating a similar user experience to that of the intended design. This prototype was continually refined based on user testing feedback and emerging design requirements. It also allowed for more technical testing to be done, along with the optimisation of wiring layouts and cover dimensions.

Conclusion

This project was very enjoyable, and a great way of putting into practice a lot of what I have learned over my time at University.

I think that the height adjustment system designed is a genuinely viable solution that future self-balancing wheelchair developers should consider adopting.

I am also especially happy with my steering column redesign, as the project culminated in a simplified version of it being manufactured and gifted to a member of the self-balancing wheelchair user group I collaborated with throughout the year. This product has greatly benefitted him already, allowing for far easier operation of his wheelchair. Images of this product in action are shown on the right.

The manufacture of this steering column, along with the large amount of physical prototyping done in this project, was made possible by funding from the 'GU68 Engineers Trust'.

Handle stored in side holster, allowing for unobstructed transfer

Handle inserted into stem, ready to use for steering

Product in use

References

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Note that the actual company website was down for maintenance at the time of writing this report. The image is usually accessible from: www.allaccessmobility.co.uk

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