Assistive Modular Aiming and Triggering System

Final Report

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Abstract

The ability to move and manipulate a wide range of objects is a crucial step in disabled people's path towards full independence, especially for those experiencing a high level of physical impairment.

However, a single prosthetic device or exoskeleton could hardly represent the "one shoe fits all" solution for patients at various stages of different neurodegenerative disorders, who often face a broad range of very diverse symptoms. For this reason, motor neuron disease (MND) patients in the early-advanced stage of the disease progression were chosen to be the primary targets of this project.

The original objective of creating a modular aiming and triggering system was therefore redefined to better suit the newly chosen user target. This was done by focusing on two main aspects of the patient's mobility, more specifically arm movement and hand grip.

The arm support system was designed with two fundamental objectives in mind: easing the users off the gravity force acting on their own arm and allowing all degrees of rotational freedom. The former was achieved through a mechanism consisting of a four-bar structure linked by elastic bands, which allowed extra support in elevation movements. The latter was obtained by placing a variety of hinges and knobs at strategic positions on the arm support, providing the user with full control over arm movements in any direction. The arm support was then to be mounted on the user's wheelchair by means of an adjustable clamp-like attachment, which ensured firmness and sturdiness to the whole device.

Independent control of hand grip was addressed by means of a hand triggering system, using pressurised actuators mounted on the patient's hand with a special strap. Deflection in the actuator could be changed by vocal control, enabling the patients to achieve different degrees of finger bending and exert different forces on the grasped objects.

Unfortunately, due to the COVID-19 pandemic, the project was forced to be suspended. Prototypes of both designs were individually tested in the lab, but it was impossible to get any final feedback on the finished product from MND patients due to lockdown measures.

Acknowledgements

The development of this product was made possible through the support of the AceCentre, Royal London Hospital and Imperial College London.

Special thanks to Dr. Warren Macdonald and Dr. Ian Radcliffe for their guidance and support throughout the duration of this project, to Dr. Firat Güder for his advice during the early stages of design, to Dr Vardakastani for her advice regarding hand movements and to Pascal Egan, Niraj Kanabar and Ji Young Yoon for their constant assistance with the manufacturing stages.

1 Introduction

Disability is a state of reduced functioning due to health conditions, which is experienced as an impairment in the context of one's environment. [1] Originally for stroke patients but applicable to other patients, the Barthel Index uses a scoring system to measure the degree of disability by using a scale to measure the level of independence a person has in performing basic activities of daily living. [2] The higher the score, the higher the level of disability.

From the project brief, the team identified disabilities associated with muscle weakness as a broad definition for high level disabilities, and later narrowed it down to persons with Motor Neuron Disease (MND) who require a wheelchair. The key idea of the product was to provide additional support for the arms of users, promoting independence and enabling them to aim for and grab an object through a trigger command.

1.1 Background Research into User Needs

Disabilities associated with muscle weakness such as MND, Parkinson's Disease, Muscular Dystrophy and Multiple Sclerosis were researched on and discussed. MND was focused on as the team had direct contact with MND patients and caregivers. This interaction allowed the team to further tighten the scope of the project brief to meet user needs, developing a product that will be beneficial and of use to them.

MND groups a variety of diseases which manifest themselves through the death of motor neurons, rapidly limiting the ability for messages from the brain to reach muscles in the body, leading to paralysis and death typically within 2-3 years within developing symptoms.[3] MND presents itself unpredictably in most patients, however weakness in grip, arms and shoulders is typical initially, amongst slurred speech and more. In the latter stages of the disease patients are wheelchair or bed bound with minimal movement and difficulty even talking or breathing. With no known cure for MND, the main aim with treatment is to increase the quality of life by improving mobility and independence for as long as possible while also keeping patients out of danger.

MND Clinic Visit

The team proposed plans for a wheelchair attached eye-gaze or touch screen controlled robotic arm, as this required minimal physical effort. Through using interchangeable modules, the user can operate different objects in line with the brief. A visit to the MND Clinic at the Royal London Hospital was made with the main aim to understand the abilities, difficulties, and desires of the patients, and get their input on the design.

The caregivers and medical personnel explained that the patients were mainly early stage, as latter stage patients find it increasingly difficult to come to the clinic. Furthermore, the staff shared the psychological effect that the patients have to assistive technology, and their aversion to using wheelchairs or crutches until absolutely necessary. Therefore, an inconspicuous and sleek device to reduce the psychological barrier was necessary.

Four patients were interviewed, one of whom was a wheelchair user. Though the types of movements were unchanged, they were limited by reach, speed and fatigue due to weakness. They could lift objects like a kettle or a phone, but it was strenuous and only briefly possible, increasingly so with the progression of their condition. Dexterous hand movements such as lifting a paper or navigating a touch screen were not possible. The patients made it clear that their main desire was to perform daily mechanical activities independently, leading the team to reconsider their initial ideas.

1.2 Aim

Typically, even from the early stages, patients experience arm muscle weakness and lack of finger dexterity, and even more so for latter stage wheelchair users. Hence, the direction of the project was changed to enable users to independently perform daily activities instead of engaging in leisure activities.

1.3 Existing Solutions

Arm supports attachable to wheelchairs that are in the market are either passive, actively-controlled or a mix of both. A passive mechanism rather than actively-controlled was found to be more intuitive and reduces technical difficulties faced. Since movements are more natural for the user, the feeling of control is preserved and the psychological barrier is reduced. The examples in *Figure 1.1*. show such gravity compensating systems utilizing elastic bands and springs. However, these products can be costly and bulky, hence the team aims to improve on these two areas.

(a) (b)

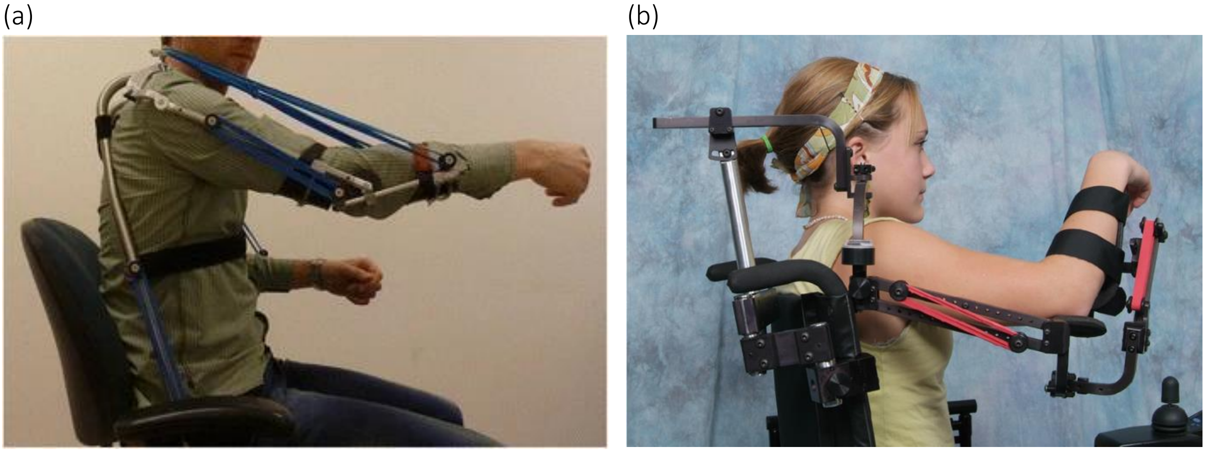

Figure 1.1 - (a) Flextension A-Gear Project. [4] (b) Jaeco Wilmington Robotic Exoskeleton (WREX) [5].

Similar glove systems exist in the research phase of development. The team initially considered string and mechanically actuated gloves, such as the Exo-Hand by Festo (*Figure 1.2(a))*. However accurate, extensible, and adaptable implementation was difficult. Hence, the team considered pneumatic actuators as they also promoted the natural feeling the patients were after. Projects such as the Wyss Institute Soft Robotic Glove (*Figure 1.2(b))* were researched, however, the complexity of their design leads to high cost.

(a) (b)

Figure 1.2 - (a) ExoHand Festo. [6] (b) Soft Robotic Glove Wyss Institiute [7].

1.4 Objectives

With the aims and problem defined, the team was split into a mechanical arm group and a pneumatic arm group. Both groups were to independently conduct research to design, prototype, and test the solution which best met the aims and requirements while simultaneously being feasible regarding the time, money and facilities available. The entire device has one overarching objective, to safely reenable as much natural and independent arm movement and hand function for the user as comfortably as possible and would be rigorously tested to this standard throughout the product development process.

2 Requirements Definition

2.1 User Requirements

2.1.1 Functionality and Performance

1. Independent aiming with the aid of the product
2. Versatility and consistent performance and safety in various objects to be grasped
3. Adaptable and modular design for different stages and intensity of disability

2.1.2 Usability, Interface and Ergonomics

4. Easy and intuitive control by user through the use of voice-controlled input
5. Accessible and easy set-up of device
6. Lightweight, natural and comfortable overall device to avoid physical or psychological impedance from device on user

2.1.3 Lifespan

7. Account for increasing level of disability over progression of disease

2.1.4 Cost

8. Keep the device as affordable as possible to allow more people to have access to it

2.2 Technical Requirements

2.2.1 Size and Weight

1. Weight of device should not unbalance the wheelchair

2.2.2 Environmental

2. Resistant to typical weather, heat, and UV conditions in Europe

2.2.3 Safety and Security

3. Use of safe materials
4. Safe usage of electrical components with fuse and cover from water
5. Smooth edges and corners

2.2.4 Reliability and Maintenance

6. Withstands daily and repetitive movements and transportation
7. Resists vibrations due to the uneven surface of the ground under the wheelchair

2.2.5 Legal and Regulatory

8. The device must meet the conditions to be classified as assistive technology and a medical device in both the UK and EU, satisfying their respective regulations

3 Final Design

The final product (*Figure 3*) consists of a passive mechanical arm and a user-triggered pneumatic glove. The former supports and amplifies arm movements, relieving users of physical strain and helping them to aim at the object. The latter enables them to grip and hold the object.

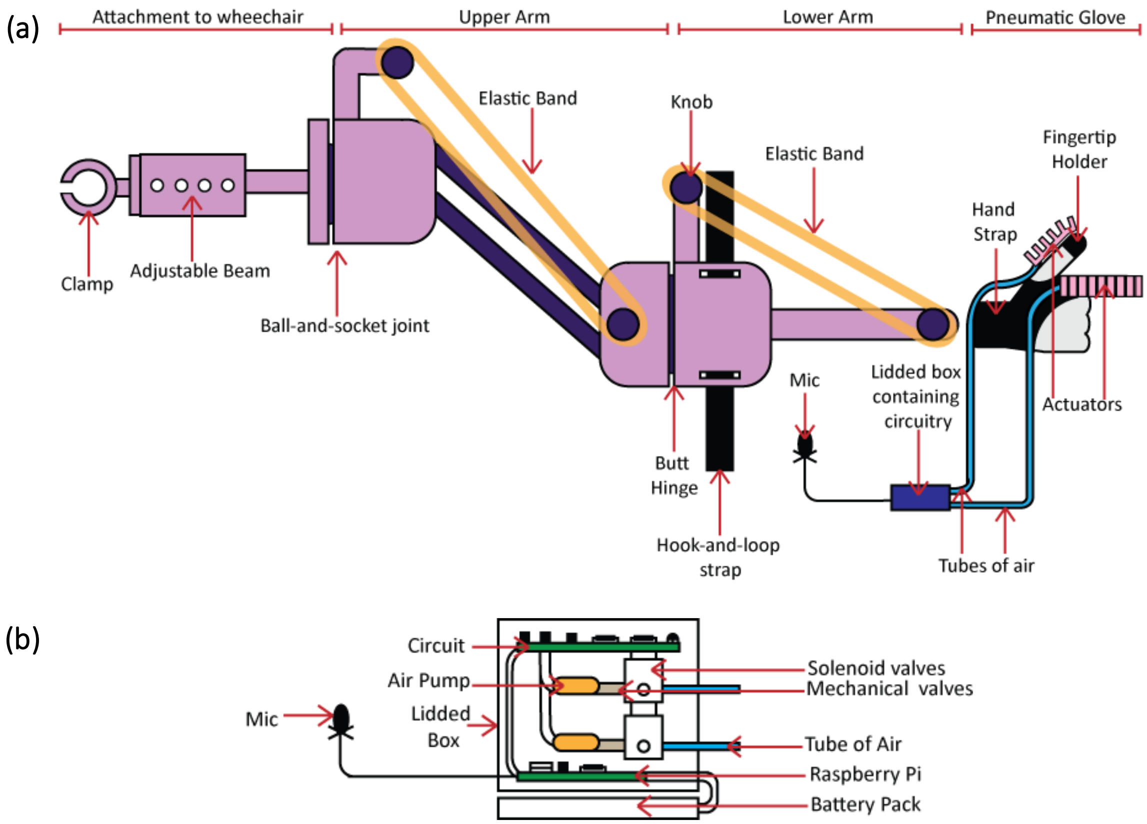

Figure 3 - (a) The final product developed. (b) The circuitry inside the lidded box.

3.1 Dynamic Arm Support

3.1.1 Design Overview

The main design idea for this component is to devise a passive arm support which amplifies the residual muscle strength of the user and retains the natural movements of the human arm. The amplifying function is achieved with a gravity-compensation mechanism characterized by the use of elastic bands, negating the gravitational downward force. The natural movements of the arm are replicated by the support thanks to several mechanisms that enable rotation at each joint.

The mechanism follows the basic structure of the arm and consists of joints, linkages, hinges, and "muscles". *Figure 3.1.1* represents the structure, broken down in three parts: wheelchair attachment, upper arm support, and lower arm support.

Going from left to right on the figure, the **wheelchair attachment** consists of a clamp to be fixed to the wheelchair, a horizontally expandable beam, and a ball-and-socket joint embedded in the upper arm support. The expandable beam of the attachment consists of two hollow structures, one sliding into the other. Holes are drilled through each structure to allow bolts to be screwed in to fix the length of the beam. The greater the overlap of the two structures, the shorter the beam becomes.

The **upper arm support** is made of two rectangular plates A and C with a four bar-linkage maintaining a fixed distance between them. Plate A is permanently kept at shoulder-level enabled by the wheelchair attachment. Plate C connects to the lower arm component via a butt hinge.

The **lower arm support** consists of Plate D and of a simple beam that stretches out to the hand. The two slits on D allow the fastening of a hook-and-loop strap around the user's elbow, and a wrist sweatband attached to the end of the beam is to be worn by the patient during use.

Both Plates A and D possess an elevated appendage (B and E, respectively). The appendages and the simple link have knobs for the attachment of elastic bands to provide force compensation to the arm.

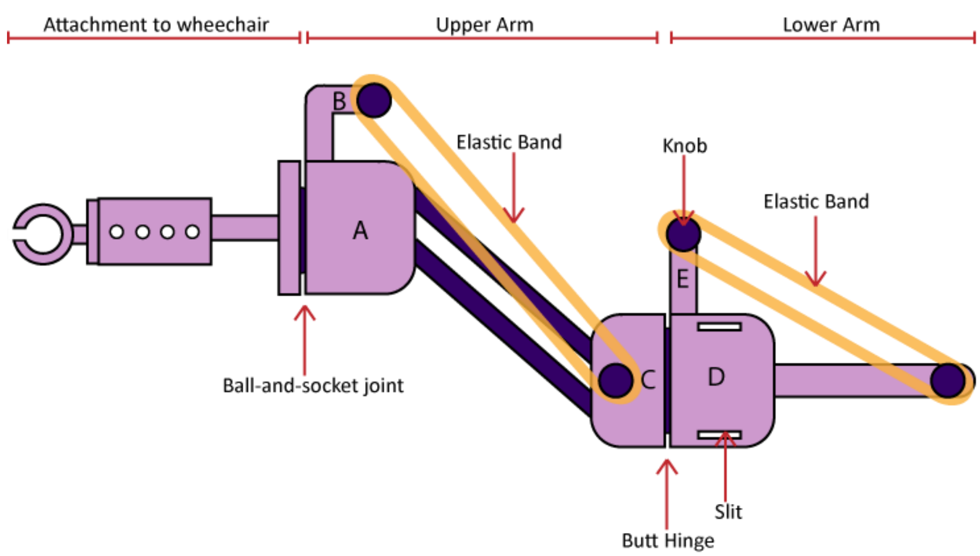

Figure 3.1.1 – 2D representation of the dynamic arm support

3.1.2 Material Breakdown

Acrylic

The main body of the arm support was initially meant to be aluminium for its robustness and lightness. However, PERSPEX® acrylic was used eventually. Firstly, the density of PERSPEX® makes it much lighter than aluminium (1.19 g/cm^3 [8] vs 2.70 g/cm^3 [9]), while retaining a good level of rigidity. Secondly, this material is quick and easy to shape in comparison to any sort of metal: PERSPEX®'s capacity of being laser-cut is a significant advantage over aluminium. Thirdly, the availability of many different PERSPEX® colours plays an important role in the psychological effect of having to use this device. Other desirable properties of acrylic include its ease of maintenance (no rust), safety (does not shatter into sharp pieces if it breaks), and ability to sustain small amounts of bending.

Aluminium

The attachment needs to be rigid and have a high failure stress for two reasons. Firstly, this is where the weight of the product, user's arm and object held will be transferred to. Secondly, the attachment is a structure that should resist the tension created by the pulling of the elastic bands. Hence, aluminium was favoured for its higher density.

Elastic bands

The elastic bands used for the final design are simple hardware shop rubber bands. These are made of natural rubber, which has a maximum elongation of 700% and offers very good mechanical properties compared to other common elastomers. Many different sizes and thicknesses can be used to suit different degrees of residual strength, depending on the patient. The number of rubber bands attached can also be modulated to adjust for different levels of strength compensation.

3.1.3 Manufacturing Process

To make the upper and lower parts of the arm support, 3mm PERSPEX® panes were laser-cut into several shapes as shown in *Figure 3.1.2*. Each part was made twice, with each pair glued together with epoxy for double thickness, hence improving bending and torsional resistance. Separate parts were then assembled using M5 steel nuts and bolts, and the butt hinge was finally fixated using M4 bolts.

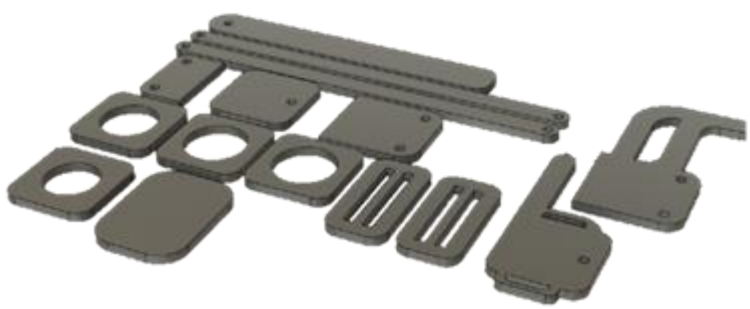

Figure 3.1.2 – CAD model of the disassembled arm support (excluding wheelchair fixation)

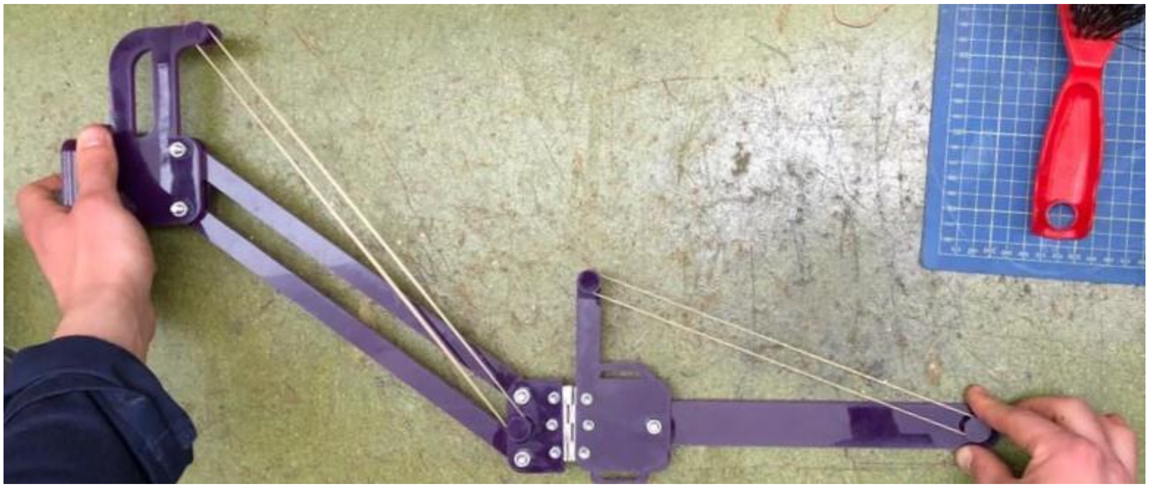

Figure 3.1.3 – Assembled dynamic arm support (without wheelchair attachment)

The wheelchair attachment could not be manufactured in aluminium due to time constraints. However, 3D printing was used throughout to test the concept of the adjustable beam (due to its hollow structure).

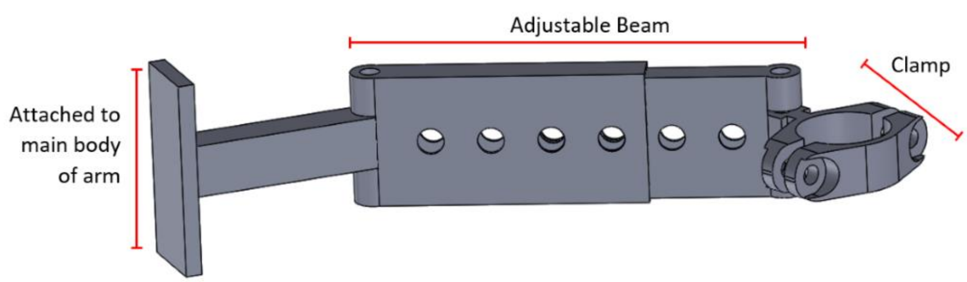

Figure 3.1.4 – SolidWorks CAD model of the wheelchair attachment

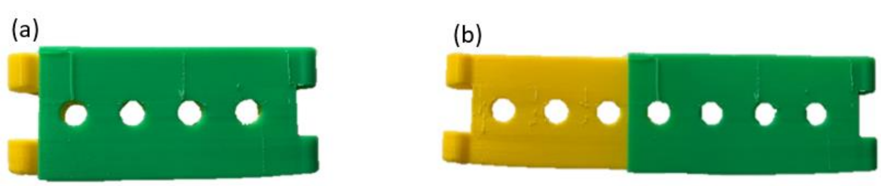

Figure 3.1.5 – Adjustable beam section of the wheelchair attachment

3.1.4 Arm Movement

The dynamic arm support should allow for the same movements and rotations as a natural arm as shown in *Figure 3.1.6*. These are: (a) Shoulder medial and lateral rotation, (b) Shoulder abduction and adduction,

(c) Shoulder flexion and extension and (d) Elbow flexion and extension, which are all present in the final product. These rotations enable circumduction (*Figure 3.1.7*) which is a mixture of abduction, adduction, flexion and extension and is therefore also achievable with the final product.

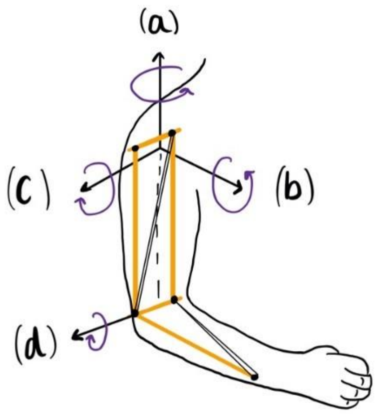

Figure 3.1.6 – Axes of rotation of the human arm

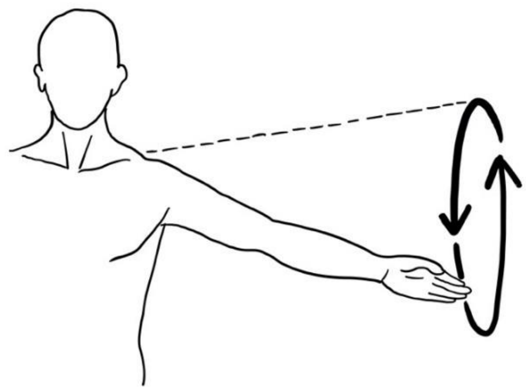

Figure 3.1.7 - Circumduction

These rotations are made possible using different types of joints. The ball-and-socket joint is a multiaxial joint which has two rounded surfaces, one encapsulating the other, that move relative to each other. This joint mimics the spheroidal joint present in the human shoulder which allows greater freedom of movement than any other joint. The butt hinge mimics the synovial joint present in the human elbow allowing the uniaxial motion about the elbow.

Working with the joints is the four-bar linkage mechanism and the elastic bands. The latter mimics the flexor muscles of the arm and amplifies the residual muscle strength of the user.

3.2 Pneumatic Hand Glove

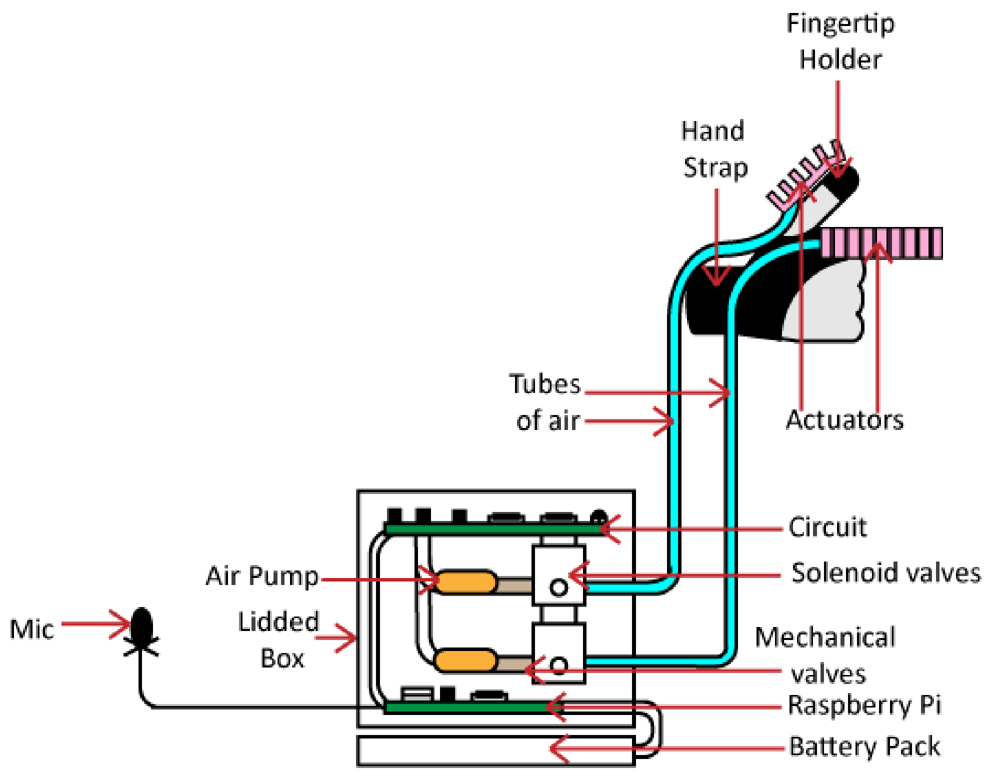

Figure 3.2.1 – An overall design overview of the hand triggering glove device

3.2.1 Design Overview

The final design that the team came up with can be outlined in the following functional components being combined to form a self-sustaining control system:

A **Raspberry Pi** controlled input system, containing a **microphone**, continuously listening for individual keywords chosen by the team and sending audio to a Google Speech-to-Text API. The microphone is clipped onto the user.

A **circuit**, which upon the recognition of a key word would have a signal sent to it via the GPIO to activate the corresponding components. The main components of the circuit were an **LED** to indicate the state of the system and 2 **pumps** and **2 solenoid valves** controlled via Darlington transistors to amplify the current according to their needs. The pumps were activated in a binary on-off mechanism to inflate the actuators, and controlled via the valves which were in series, which worked together to allow airflow in or out of the actuators or hold air in them, and the **mechanical valves** which prevented backflow of air.

The **actuators** were made by casting silicone in a 3D printed mould. The mould defined key features of the actuator, such as the height and width of the chambers, which directly affect the amount of bending. The actuators inflate due to an inbuilt air channel and bend due to having a strain-limited base. They are mounted using Hook-and-Loop on a **hand strap** which allows for maximum adaptability.

These components allow for a user to grip any object up to 1kg. The system is powered by a rechargeable **battery pack** and housed in a laser cut 3mm PERSPEX® acrylic **lidded box** where grooves in foam have been made to perfectly contour the Raspberry Pi, circuit board, pumps and valves to ensure their safety and accessibility.

The detailed mechanisms of each components are detailed below.

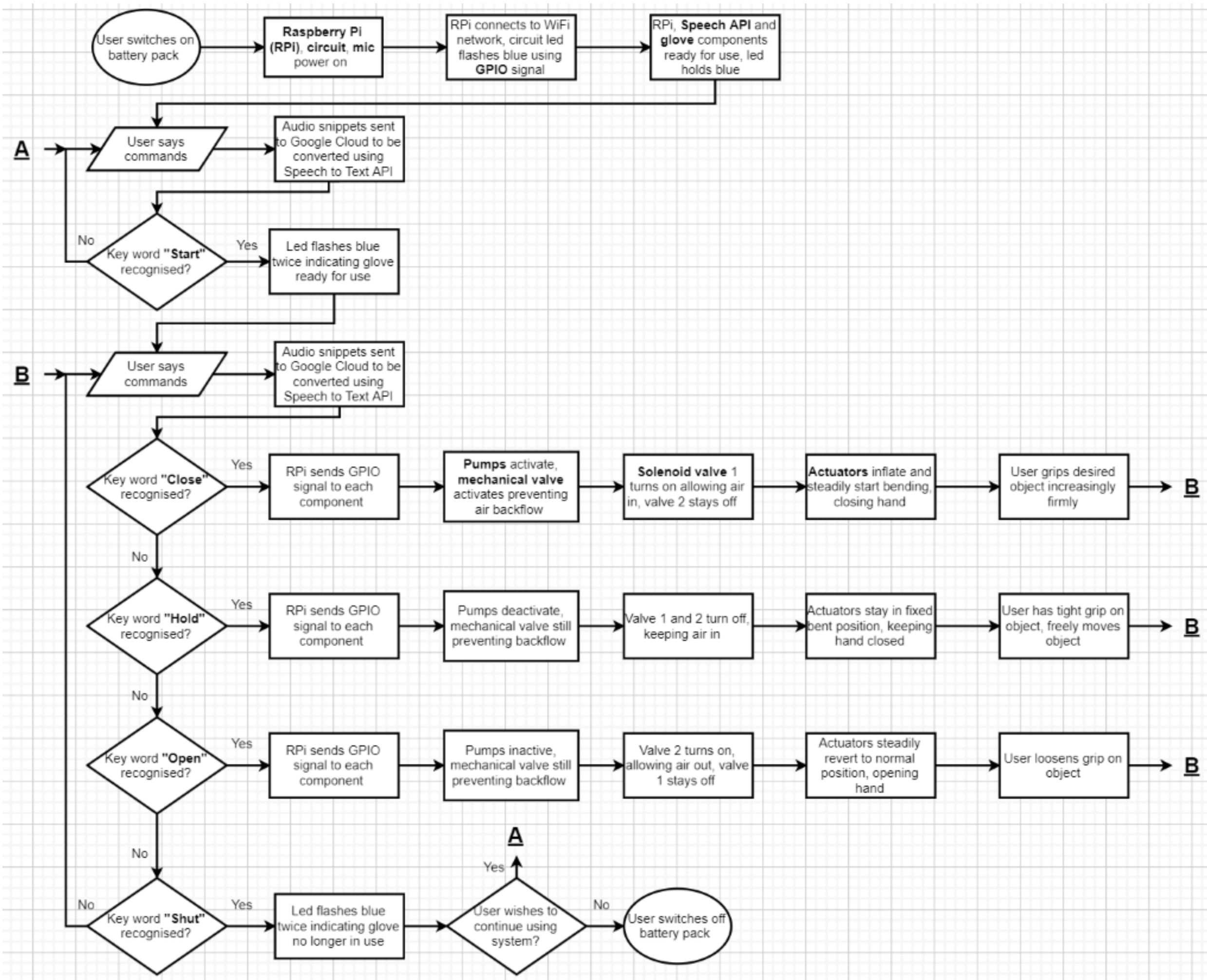

Figure 3.2.2 – A flowchart detailing the process and purpose of each functional component in the system, indicating the achievable outcomes

3.2.2 The actuator

As a key feature, mechanical actuators are responsible for the execution of the device's programmed action. It determines the performance and type of objects users interact with and impacts the device's appearance and structure.

The need to choose a light, compact and versatile actuator, where operational hardware could function distributed elsewhere, became clear. Embedded pneumatic Networks (PneuNet - *Figure 3.2.3*) [10], as proposed by the Whitesides group at Harvard, were considered to match almost perfectly to these specifications.

3.2.2.1 Structure and materials

The characteristic bending motion of actuators when pressurization occurs arises from the materials and structure of the PneuNets. The network of chambers is made from a high strain/low durometer (stretchy) material, enabling them to expand. The base, however, is made from a low strain/high durometer (rigid) material, preventing any change in length.

The actuators performance is influenced by the material used in manufacturing and its characteristic dimensions. These factors determine how much pressure is needed to cause a certain degree of bending and how much force is applied at the tip. The goal was to minimise the actuator dimensions, keeping the operating pressure as low as possible and, at the same time, maximising applied force and bending degree.

For the inflatable chambers, three silicone rubbers were considered: Elastosil M4601 A/B, Ecoflex 30 and Silicone 1. The characteristics of the three materials are summarised in *Table 3.1*.

After several considerations (See *Discussion – Silicone choice*), *Elastosil M4601 A/B* was chosen for the expansible chambers. For the base's strain limiting material, paper of thickness 0.1 mm was used. The layout of the actuator is as shown in *Figure 3.2.3*.

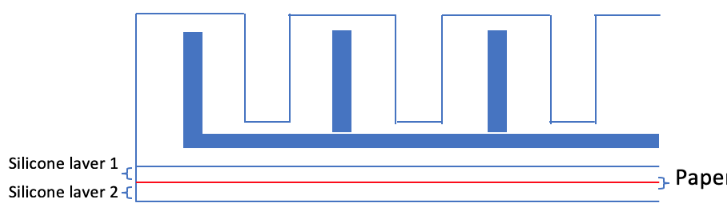

Figure 3.2.3 – Structure of a PneuNet actuator with base layout highlighted

Table 3.1 – Mechanical and qualitative characteristics of the three silicones tested.

	Unknown Silicone	Ecoflex 30	Elastosil M4601 A/B
Picture			
Producer	Unknown	Wacker	Smooth-on Inc
Shore A hardness	Unknown	00-30	28
Young's Modulus	Unknown	0.1 MPa	7MPa
Force exerted (complete bending)	++++	++	+++
Pressure (complete bending)	++++	+	++

3.2.2.2 Manufacturing

A) Characteristic dimensions

The PneuNet actuators placed on the thumb and middle/pointer finger are of the same dimensions (*Table 3.2*), which, according to tests performed and the literature [11], optimises device performance and usability.

Defining the chambers' material as a hyper elastic silicone rubber with non-linear characteristics, the Yeoh model [12] determines which parameters are more important for the actuator's performances. Panagiotis P. *et al* [11]. adapted the model to the PneuNet actuator and came up with the following relation between the force generated at a certain pressure (M_a), the expansion distance of the chambers (a) and the characteristic dimensions (***b***,***d*** – *Figure 3.2.4*):

$$M_a = b^2\left(2 - \frac{b^2}{b^2-(2a-d)^2}\right)$$

M_a: force
b: Chamber height
d: Chambers distance
a: Inflation distance

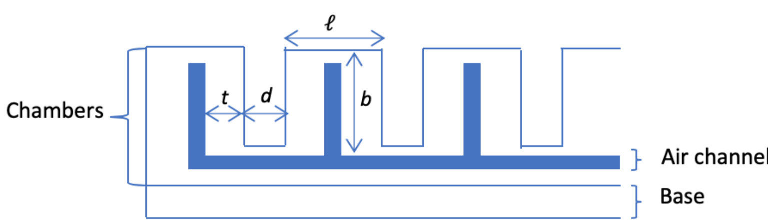

Figure 3.2.4 Structure of a PneuNet actuator with characteristic dimensions

Since M_a needs to increase for better performances, the direct proportionality with b^2 makes this parameter a key factor for the exerted force and for the degree of bending produced. Another important factor is **d** which needs to be minimised, together with **a**. For the same degree of bending, an increasing number of chambers makes the parameter **a** smaller [11]. The thickness **t** is also important in terms of pressure needed to inflate the chambers. The final actuator used has 11 chambers and its final dimension can be found in *Table 3.2*.

Table 3.2 – Dimensions of the final actuator with 11 chambers.					
b	*d*	*l*	*t*	*Base thickness*	*Width*
11.00 mm	2.15 mm	7.94 mm	1.77 mm	4.12 mm	19.75 mm

Figure 3.2.5 displays the theoretical behaviour of the pressurized actuator. The deflection is large enough to grip an object.

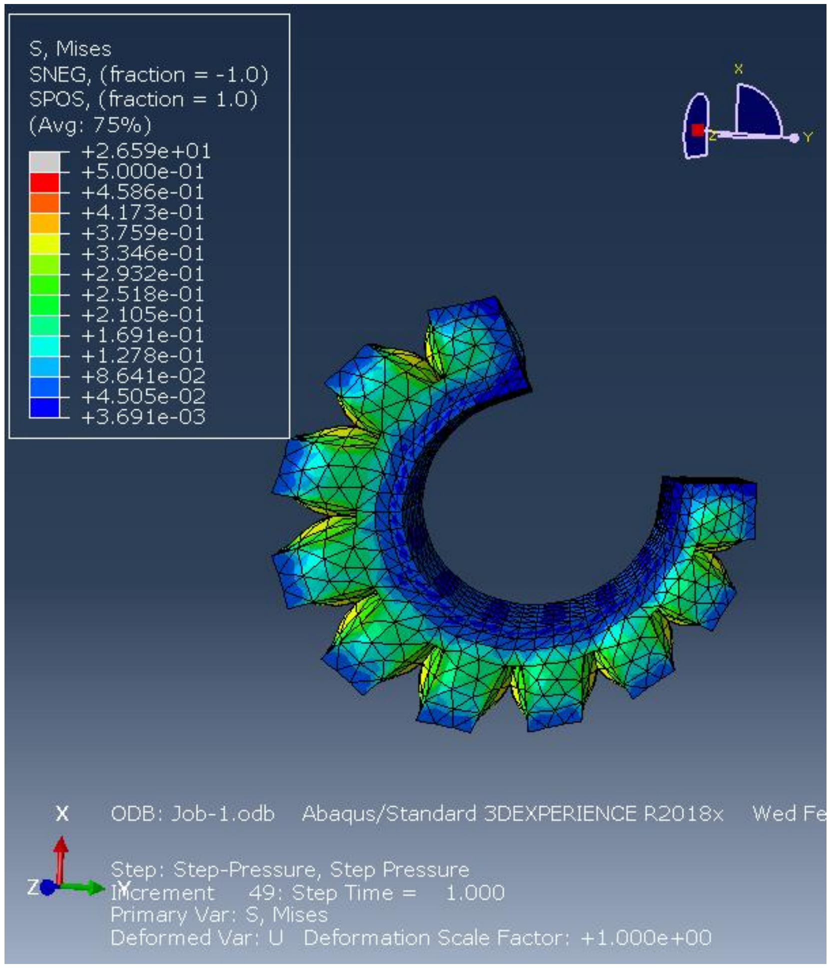

Figure 3.2.5 – Simulations of the deformation of a PneuNet actuator made of Elastosil M4601 with the dimensions stated in *Table 3.2*. The simulation was done on the abacus and shows the stresses and the deformation after injecting 55MPa of air as a step. The different colours represent the stress on the walls of the actuator.

B) Manufacturing process

The manufacturing technique encompasses mainly two steps, the 3D printing of the mould, then the casting of the Pneunet actuator. The only requirement for casting the silicone is a vacuum room, to degasify the silicone and avoid the formation of bubbles, and an oven at 65°C to decrease the solidification period, otherwise 24 hours long.

The moulds consist of three parts, two for chambers casting (*Figure 3.2.6(a), (b)*) and one for the base (*Figure 3.2.6 (c)*). Parts a and b are assembled, filled with silicone and put in the vacuum room for 10 minutes. The same procedure is applied to the base part, with the only difference that only half of the mould is filled with silicone in order to make Silicone layer 2 (*Figure 3.2.3*) first. The moulds are then placed in the oven. After 20 minutes in the oven at 65°C, the silicone is solidified, and the chamber part is extracted from moulds (a) and (b). A layer of paper of the same shape of the base is laid on the first layer of silicone and the other half of the base is filled with silicone, in order to make a layer thick enough for the chamber part to adhere to the base part, completing then the PneuNet manufacturing.

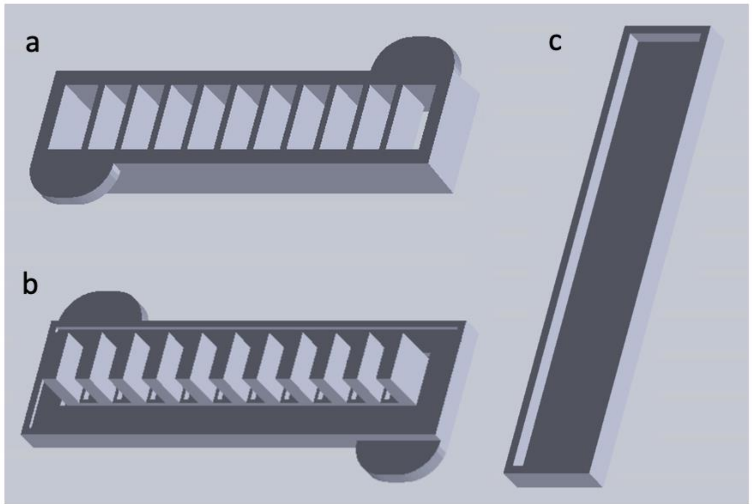

Figure 3.2.6 – Mould components for casting the actuators. (a) and (b) are assembled to make the chambers, while (c) is used for the base.

A nozzle (*Figure 3.2.7*) was designed and 3D printed to avoid any air leakage at the actuator inlet.

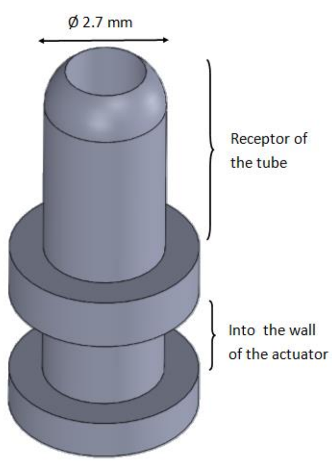

Figure 3.2.7 – Nozzle linking the actuator and the 3mm tube connected to the pump

3.2.3 The User Input

The user input needs to require the least physical effort due to the nature of the disease. Since joysticks are not possible, voice input and eye-tracking were considered. The most efficient mechanism relative to its implementation complexity was voice input.

The voice control of the actuators is done with simple keywords, "open", "close", "hold", "start", and "shut". These were chosen due to their relatively low difficulty in pronunciation, being only 1-2 syllables, as many latter stage patients slur.

For the device to understand the user's commands, the Python codes relevant to the access of the Google Cloud Speech-to-Text (STT) API of the Google AIY project [13] were accessed and run on the image of the Raspbian Operative System (OS) installed on the microcontroller Raspberry Pi 3B+. With the microphone, the user input speech is converted to text. If any of the keywords are matched, individual components are triggered, and the device hardware is activated as outlined in the flowchart (*Figure 3.2.2*).

An LED was used to alert the user of the state of the device, such as if the Wi-Fi was connected, if the device was actively listening, or if the power was low. Related code is in *Appendix G*.

3.2.4 Circuit

The team built an open-loop electro-pneumatic circuit, controlled by inputs from the Raspberry Pi, that efficiently provided for the actuator's desired functionality.

For electronic airflow control, solenoid valves, conventionally used for such a task, were used. They permit or prevent airflow with the help of a solenoid, which is activated by an electric current. Normally closed-direct acting valves requiring 6.5 W to operate were used in this circuit, opening when a current is applied. The valves were small, medium-weight and cheap. Furthermore, air pumps were required to fill the actuators with air. RS components 4.5 V pumps were chosen for their lightness and low power consumption of 0.48 W. The pumps also proved to be effective in controlling the actuator since the air outflow rate was low, giving the patient more time to terminate air flow into the actuator. These electrical components were combined with tubing and mechanical no-return check valves to obtain an ideal, cost-effective solution to control the airflow.

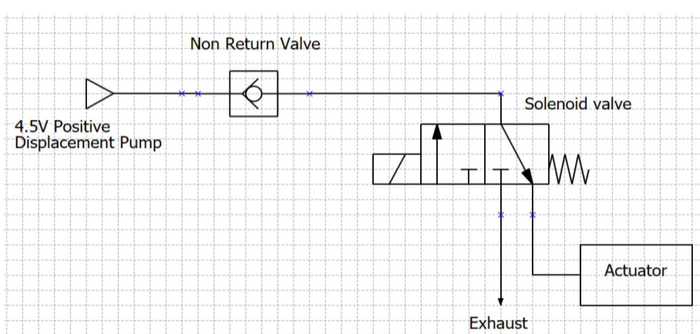

Figure 3.2.8 – Schematic of pneumatic circuit to control air inflow into the actuator.

The electronic circuit for the control components was designed in a modular way, applicable to each device. To activate either the solenoid or the pump, a Darlington transistor was used. A small input current from the Raspberry Pi GPIO was used to switch on the transistor, amplified and drawn by the device. A 12 V battery powered the solenoid, and the 5 V output from the microprocessor powered the pumps. To eliminate transient voltages arising from the solenoid or the pump motor, a flyback diode was used.

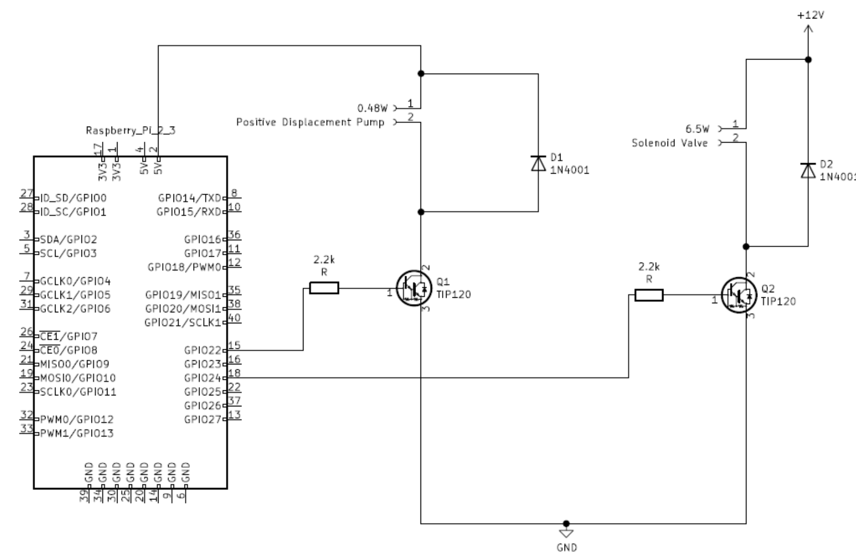

Figure 3.2.9 – Schematic of the electronic circuit to control the solenoid valve and positive displacement pump; control unit for one actuator.

The circuit was drawn up and simulated using OrCAD. The values of the resistors in the circuit were chosen in accordance with the power requirements of the components and the characteristics of the transistors. After creating a breadboard-based design, a prototype for a printed circuit board was created. The design was small, stable, and could be stored in a box together with the other circuit components.

3.2.5 Hand attachment

The hand is involved in complex movements, making it hard to implement a device that replicates all movements. Hence, the team focused on the tripod grip which allows the user to handle most objects. This grip is achieved by placing and joining actuators of the same size on the thumb and between the pointer and middle finger.

A soft, strap-like wrist splint made of neoprene was used. Two rings of neoprene were cut and placed on the thumb and the pointer/middle. The actuators were then attached at one end to these rings, and at the other end to wrist splint using Hook-and-Loop straps. The main advantages of this design are the increased sensitivity to touch, since most of the inner side of the user's hand was left uncovered, and the possibility to adapt the actuator's position to any hand size.

4 Testing and Evaluation

Some tests on the product were not possible due to the outbreak of COVID-19 and because the wheelchair attachment was not manufactured yet. Ideally, its performance would have been evaluated by means of the tests described below.

Arm Component

Firstly, safety and durability are tested by gradually increasing the load at the end of the arm support and recording the failure load. For the arm support to be reliable, the failure load should not be below 3kg (combined weights of the gripping glove with that of a medium- weight object). This test includes two independent variables – load and number of elastic bands – and therefore needs to be repeated multiple times.

Secondly, a torsional strength test is conducted for the beams linking the joints of the arm support. This is because these components are long compared to the others making up the arm support and are thus more prone to torsional stress and failure when a load is applied asymmetrically. For the test to be successful, failure should not occur under nominal torque values of 7Nm and 9Nm, for the forearm and the upper arm beams, respectively.

Glove Component

Firstly, the 5 different voice commands were tested, and the circuit components responded as expected.

The actuators were tested at 55 MPa. The main problems encountered were blocked air channels and air leakage through the inlet valve. If not faulty, the actuators were able to curl completely.

To assess the durability of the actuator, a repeated activation of the actuator would need to be performed. It is already provided that after repeated activations at 2 Hz frequency, the actuators do not fail after 10^6 cycles and that their life span is longer than what possible to record [14].

To understand the weight limit of a held object and to determine the grip strength applied by the actuators, a grip test would with a dynamometer need to be made

Overall Product

User feedback is crucial to find out if the overall device works as desired. Users would be asked to lift their arm as high as possible with and without the arm support. The angle between the arm and the body would be recorded. A successful arm support would be one that has a greater angle of elevation when wearing the arm support compared to when not wearing. Similarly, for the glove, users would be asked to take, hold and release several commonly used objects of weight not exceeding 1 kg. These objects would have different shapes (playing cards, a pint of beer, a glass) to test the modularity of grip.

The team considered the Jebsen tasks to evaluate the functionality of the product. There are 7 tasks: (1) Writing, (2) Turning cards, (3) Small objects, (4) Feeding, (5) Stacking, (6) Light objects and (7) Heavy objects. Users are timed on how long they take to complete each task with and without the product. After which, they will be asked to provide feedback using the questions listen in *Table 4*. [15]

Table 3 – Questionnaire to qualitatively evaluate performance of product

1. Did the orthosis perform well?
2. What would you change about the orthosis?
3. How much did you use the device daily?
4. Did you like the way the orthosis looked, why or why not?
5. What tasks did the device help you do?
6. Would you like to have such a device?
7. Did the device make you tired?

5 Discussion

5.1. Shortcomings and Improvements

<u>Arm</u>

Because of the reasons already stated above the dynamic arm support could not be tested, hence its performance impossible to evaluate. However, some shortcomings of the design were identified and pave the way for improvement.

The biggest issue with the arm support is the direct exposure of the elastic bands to the user. No safety measure was taken to ensure protection from the elastic bands snapping under high tension or fatigue failure. This problem is double-sided: not only would the snap cause a lash against the user, there would also be a sudden loss of support and any object held at the time of failure could potentially drop to the ground. The former risk can be mitigated by adding a solid sheath between each pair of knobs, such that the elastic bands would be encased and not able to snap outside of this new compartment. The case would require a lateral “door” to replace the bands and transparent walls to monitor them. The latter issue is not major because the arm support already requires multiple (>5) elastic bands to function, hence failure of one of these would have no consequence other than a slight downward “sag”.

A second issue is the lack of proper support at the forearm or wrist area. A simple wrist sweatband might not be sufficient to support the weight being transferred from the shoulder to the forearm. A built-in structure allowing the forearm to rest would enhance the gravity-compensation effect.

The beams making up the four-bar linkage mechanisms can also be made adjustable to suit different arm lengths. Having a good fit of the arm support on the user’s arm would enable more natural movements of the arm and increase comfort. An expandable beam similar to that of the wheelchair attachment would provide this adaptability.

<u>Glove</u>

Silicone choice

The silicone used to manufacture the PneuNet actuators is a key factor in terms of performances. The three silicones (*Table 3.1*) considered were deeply analysed both through qualitative considerations and past literature [9].

The *Ecoflex 30* is softer compared to *Elastosil M4601 A/B* and it is showed that, an actuator with softer chambers requires 8 times less pressure to bend completely. However, it will need 1.5 times more change in volume and more time to bend [9]. The stiffer actuator will however exert more force, and therefore more suitable for the group's purpose.

Comparing qualitatively unknown *Silicone* and *Elastosil M4601 A/B*, the former is stiffer and able to exert more force. However, the pressure required to bend it completely is almost double the one needed for the softer actuator, making the unknown *Silicone* unsuitable in terms of air pump power. Thus, the final actuators were made with *Elastosil M4601 A/B.*

Manufacturing Technique

The manufacturing technique imposes a limit on how small some parameters can be. Indeed, 3D printing the actuators directly with silicone rubber has a more accurate outcome and allow parameters such as ***t*** and ***d*** to be small, but with a higher manufacturing cost. In contrast, making moulds of the actuators and casting them makes the outcome less precise, but more affordable. The latter was used for budget and time reasons.

User inputs

The most important consideration here is the latency between the voice command and the pump activation, which is around 3 seconds. Firstly, Python was used to enable the recognition and actuation of a command. Being an interpreted language, its performance is inherently poorer than a compiled language such as C++ which would certainly improve the latency. Secondly, the glove continuously communicates with the Google Cloud which, on top of introducing a Wi-Fi dependency, may also add to the latency from suboptimal connections. To solve this, the team can implement Mozilla DeepSpeech, which is a powerful offline STT engine improving performance. Furthermore, a self-implemented engine can be trained on user data sets and continuously updated to improve and maintain recognition accuracy, even in latter stages.

Finally, uniquely afflicted or latter stage patients will be unable to efficiently use voice input. Therefore, future considerations regarding alternative interfaces to accommodate user needs are important and should aim to improve the device's interface modularity and adaptability.

5.2 Group Working

The idea of teamwork and group cohesion have been on the group's utmost priority throughout EDP. Hence, the group went through big changes to uphold the importance of group work. The major change was the redefinition of user requirements, project aim and work allocation a month after the commencement of the project.

Meetings were then held twice a week or ad-hoc if there were serious matters to be discussed. All meetings were prepared with an agenda circulated before meeting. Minutes were typed up by the secretary and action points of the meeting were sent out to the messaging group to ensure the highest efficiency and transparency within the group.

The thinking process could be further improved if roles had been more clearly defined from the start. The position of the project manager was long vacant until the team re-entered the thinking process. The group was unfortunately easily side-tracked and went off topic during meetings for the first few weeks.

Furthermore, the project manager's role could be further enhanced if he was able to contribute into both teams. Initially, the project manager was only added to the arm group and the main group on the messaging application, which eventually led to a lack of communication among group members.

To conclude, the group managed to work together seamlessly in designing and making of the required components to achieve the requirement specification first outlined. Prototypes from both teams were to be tested as working, with the improvements to be made.

Arm support team

The group working on this part of the project was very effective insofar as the conceptual design and prototyping of the arm support are concerned. Much attention was put into seemingly small but very important details, such as:

- How to make the wheelchair attachment as adaptable as possible?
- What positioning of the knobs is better for optimal weight compensation?
- Which axes of rotation are the most important and which mechanisms can implement them?
- How to keep the user's arm fixed to the support without excessive friction?

Such questions, and many others, were mainly answered through intensive prototyping and experimenting on the group members themselves. This allowed the group to directly detect the flaws of the designs, rather than predict them with excessive calculations and approximative guesses.

While this method made the final design very user-friendly and ergonomic, it also represents a major strategical problem in retrospective. So much effort was put into prototyping and empirical testing that the more "theoretical" aspects of the project were somewhat neglected – useful tools such as computational simulation and finite element analysis.

The main reason for this is because of a suboptimal division of tasks in the five-member team. As seen in Appendix A, the assigned roles were very general and were given to multiple team members at the same time. For example, two members were in charge of the wheelchair attachment design, but this meant that these two members had to learn all the skills necessary for the design process, which felt overwhelming.

In contrast, if a specific skillset were assigned to each member individually (for example *"finite element analysis"* or *"CAD assembly and mating"*), the workflow would have been much smoother and the overall design process less overwhelming for everyone. This would also have permitted the team members to learn from each other, as each person would have become a specialist of a particular design tool instead of a "*Jack of all trades"*.

Glove team

The group working for this part of the project followed a sequential path. Initially, research was carried out to explore different solutions for hand gripping and triggering. A large body of research was collected and summarized.

The group was keenly aware of the constraints imposed on the project, such as available know-how and materials. Targets that initially seemed far-fetched, such as defining too broad a target group, became increasingly refined as more user data and design knowledge was gathered.

The manufacturing process highlighted several positive attributes about the group. The required tasks were clearly defined and allocated according to individual skill sets. This allowed for the use of a wide range of manufacturing methods, ranging from 3D printing to circuit making. A list of weekly aims was created to streamline group working and increase efficiency. Moreover, the group was inclusive and open to new suggestions. This allowed for the exploration of new ideas and the addition of components to the designed product.

Only minor issues arose during the progression of the project. Firstly, as the final design was created at a relatively late stage due to corrections, the procurement of the required components was delayed. In the end, however, all required components were successfully acquired.

6 Conclusion

After numerous trials and tests, the project has evolved from models to working prototypes for both the arm aiming and hand triggering. Various challenges were solved along the way, from improving stability and material of the component, to enhancing the freedom of movements in arm aiming and the accuracy of actuation movement.

Both products of the teams were individually tested in lab and with simulation software. The next step would be to integrate compartment boxes, clamps etc all together into one sleek design to be fully incorporated into the wheelchair.

Unfortunately, the engineering design project was forced to cut short due to unprecedented situation of the COVID-19. The working prototypes could not make their way to targeted-user testing as they were never fully integrated together, however ultimately, simulative and non-targeted user testing proved the success in the designs of both prototypes.

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Appendix A - Project Management

The progression of the project can be divided in two broad phases:

1. Identification of user requirements and overall design discussion
2. Specific design and manufacture

Phase 1 consisted of whole-group biweekly meetings with the aim of defining the best possible approaches to tackle the user requirements which were being gathered in parallel (from hospitals, emails and phone calls, which took a certain amount of time). This brought about a first division of labour to suit each member's skills and interests:

- Project manager - Allan
- Organiser - Theo
- Procurement manager - Carlota, Fabio
- Manufacturing manager - Alice, Alessandro, Leo
- Resource collector - Nicolas, Abdullah
- Secretary - Jaynell

Although these roles were assigned to specific team members, it was not uncommon for others to bring their support in a task lying outside their given responsibilities. Overarching design decisions were always made as a group, each member bringing his/her own ideas to the table.

Due to the double-faceted nature of this project, the group was also divided in two teams to allow a more directed focus on design decisions for each component:

Hand triggering system

- Abdullah - User interface development and I/O integration, Circuit box components organization
- Alessandro - Circuit box components organization, Hand strap manufacturing.
- Alice - Actuator and actuator moulds design and simulation, Electronic circuit design
- Fabio - User interface development, Actuator manufacturing
- Nicolas – Electronic circuit design, Circuit box components organization

Dynamic arm support

- Allan - Arm support mechanism design, Prototype manufacture and general supervision
- Carlota - Wheelchair fixation component design, Initial ideation
- Jaynell - Wheelchair fixation component design, Prototype manufacture
- Leopold - Arm support mechanism design, Prototype manufacture and final product manufacture
- Theo - Arm support mechanism design, Final product manufacture

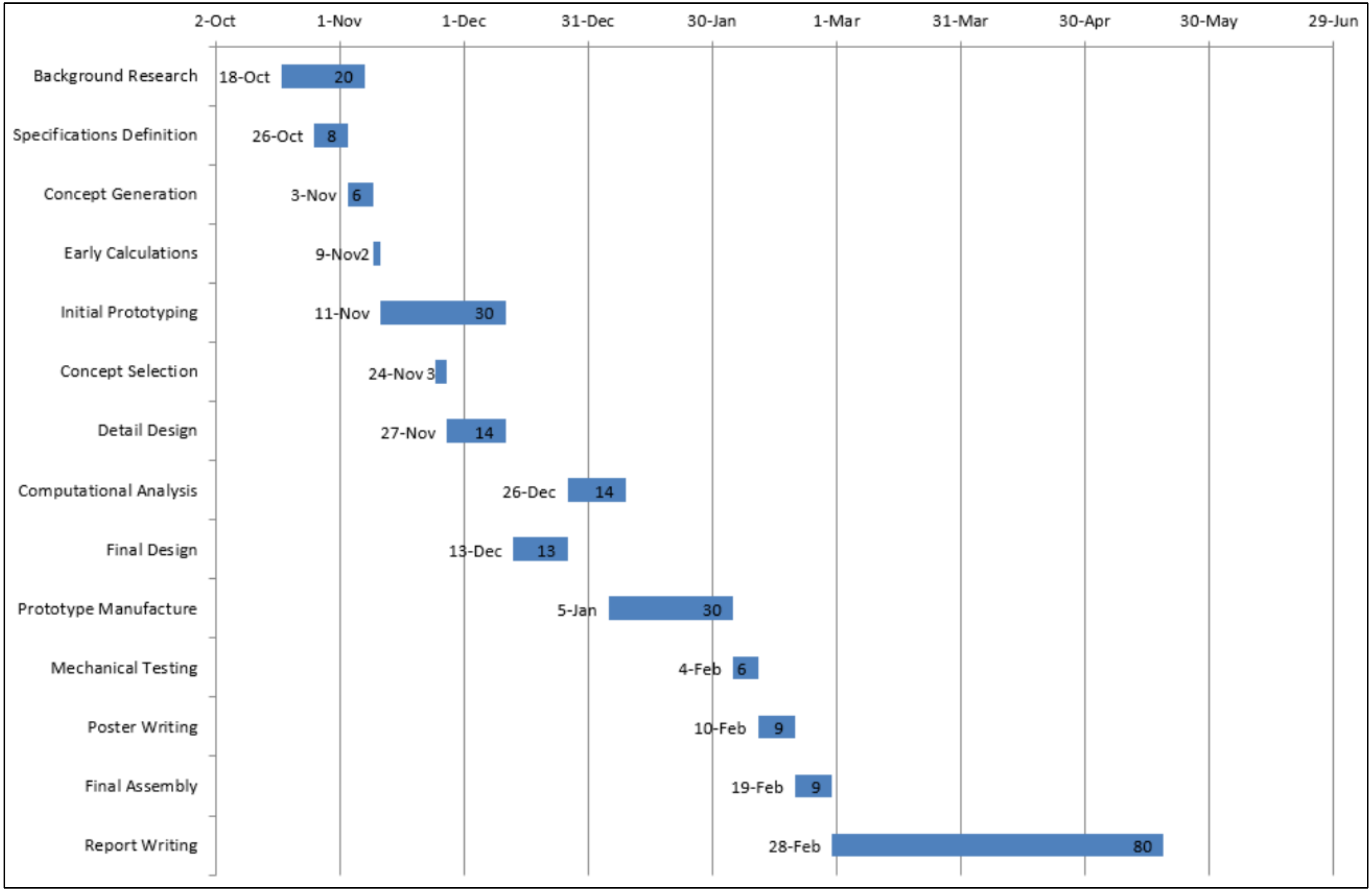

Figure A – Gnatt Chart

Appendix B - Risk Management

Critical Risk Priority Number

During the risk analysis, each risk or failure is analysed and rated with respect to its severity (S), probability of occurrence (O), and detection rate (D). The rating for each of the three aspects ranges from 1 (low security risk/failure, low probability of occurrence, high detection probability) to 10 (severe injuries or death, high probability of occurrence, no/low probability for detection). The product out of these three ratings is called Risk Priority Number (RPN). In case, the RPN is greater than a critical threshold, preventing measures are required in order to reach a final RPN below or equal to the critical threshold by means of reasonable and justifiable security measures.
Define a critical threshold in this section here – we recommend a critical **RPN threshold of 75**.
In case, the risk is greater than the critical threshold the risk **must clearly be mentioned** in the "declaration of agreement" signed by the pilot and involved staff.

Factors of the Risk Priority Number (RPN)

Find below a recommendation how to rate occurrence, severity, and detection. The "Risk Priority Number before "is a mathematical product of the numerical Severity- (S), Occurrence- (O), and Detection-Ratings (D) obtained before applying any preventing measures to reduce the likelihood for dangerous incidents, thus: **RPN before = (S1) x (O1) x (D1)**. This "RPN before" should be set to prioritize items that require additional quality planning or action.
The "RPN after" is a mathematical product of the numerical Severity- (S), Occurrence- (O), and Detection-Ratings (D) obtained after applying the preventing measures to reduce the likelihood for dangerous incidents, i.e. **RPN after = (S2) x (O2) x (D2)**. The "RPN after" has to be equal or below the predefined threshold in order to guarantee safe use of the part/element/device.
Preventing measures are mechanisms that prevent the cause of the failure mode from occurring or that detect the failure and stop the application before an incident can happen. It could also reduce the severity by e.g. designing softer and rounder edges. Preventing measures could include specific inspection, testing or quality assurance procedures; selection of other components or materials; de-rating; limiting environmental stresses or operating ranges; redesign of the item to avoid the failure mode; monitoring mechanisms; performing preventative maintenance; or inclusion of back-up systems or redundancy.

S – Severity

Rating S	Criteria: Severity of effect	Consequence	Treatment
10	Death	-	-
9	Quadriplegia	Life-long medical care necessary / coma permanent damage	/Hospital stay
8	Amputations, paraplegia, blindness, deafness, traumatic brain injury (severe), fourth-degree burns	Life-long medical care necessary / coma permanent damage	/Hospital stay
7	Complex fractures, open fracture, inner injuries, traumatic brain injury (severe), third-degree burns	Permanent damage possible	Hospital stay
6	Gash, fractures, torn muscles, articular cartilage injury, traumatic brain injury (moderate), second-degree burns	Permanent damage possible	Hospital stay
5	Gash, fractures, torn muscles, articular cartilage injury, traumatic brain injury (mild), second-degree burns	Reversible injury	Hospital stay or ambulant treatment
4	Severe cuts, severe scratches, severe contusions, strains, first-degree burns	Reversible injury	Ambulant treatment or self-treatment

3	Minor cuts, minor scratches, minor contusions, stiff muscles, tension, blisters, excoriations, sickness, first-degree burns	Discomfort during application up to three days after application	Self-treatment
2	Slight sickness, pressure marks	Discomfort	-
1	No harm	-	-

O – Occurance

Rating O	Criteria: Probability of occurrence
10	Occurs or may occur very likely during every use of the session
9	Occurs or may occur likely during every use of the session
8	Occurs in 1 of 5 sessions (less than once a day)
7	Occurs in 1 of 10 sessions (less than once a day)
6	Occurs in 1 of 50 sessions (less than once half a month)
5	Occurs in 1 of 100 sessions (less than once a month)
4	Occurs in 1 of 500 sessions (less than once half a year)
3	Occurs in 1 of 1000 sessions (less than once per year)
2	Occurrence very unlikely
1	Occurrence nearly impossible

D – Detection

Rating D	Criteria: Likelihood of detection by design control
10	No chance of detection
9	Very remote chance of detection
8	Remote chance of detection
7	Very low chance of detection by indirect methods (hardware or software)
6	Low chance of detection by indirect methods (hardware or software)
5	Moderate chance of detection by indirect methods (hardware or software)
4	High chance of detection by indirect methods (hardware or software)
3	High chance of detection by direct or indirect methods (hardware/software)
2	Direct and indirect detection: Hardware or software
1	Direct detection: Hardware or safe software (category 4, performance level e)

Risk Analysis Table

Assembly	Failure & Effect	S1	O1	D1	RPN before	Preventing measures	S2	O2	D2	RPN after
Arm support	Elastic failure: elastics snaps skin, arm is no longer sustained	3	5	1	15	Multiple strong elastics to prevent arm falling if one fails	2	4	1	8
	Rigid bodies (acrylic parts, hinges, wheelchair support) failure: arm no longer sustained, sharp cutting edge at fracture ends	4	3	1	12	Edges are smoothed to prevent cutting	4	2	1	8
	Improper setup of the elastics: arm too tight or not stretched enough	2	3	3	18	No further measures necessary	2	3	3	18
	Oxidation of metal parts (hinge and bolts): formation of rust	3	4	2	24	Stainless steel used	3	1	2	6
	Sensitive skin itches due to long contact with some materials (acrylic, rubber bands, metal)	3	2	4	24	Materials have passed multiples norms	3	1	4	12
	Vibrations causing rupture/weakening of certain parts	2	6	3	36	Counterbores to prevent unscrewing bolts	2	4	3	24
	Torsion of arm support	5	2	1	10	Rigidity of some materials enhanced	5	1	1	5
Pneumatic Glove	Increase in pressure causing tubes connected to PneuNet actuators to come off.	1	9	5	45	Nozzles mounted with silicone at the inlet where tubes can be better secured.	1	6	3	18
	Skin irritation due to long time wearing.	2	2	4	16	Using highly tested materials that prevent skin damages.	2	1	4	8
	Thumb distortion due to PneuNet actuator wrong positioning.	3	2	5	30	Producing a detailed guide on glove assembling highlighting the eventual problem.	3	2	3	18
	Accidental activation of PneuNet actuator due to conversations of other people	1	2	3	6	Implement voice recognition so that it allows command of only the specific user	1	1	3	3
	Transient voltages due to the solenoid or the pump motor harm the circuit.	4	8	2	64	Introduce a snubber diode.	4	1	2	8
	Circuit malfunction resulting in a short circuit and damage.	5	3	2	30	Include a fuse in the circuit.	5	1	2	10
	The actuator inflates too quickly, and the patient may not have enough time to terminate inflation.	3	9	1	27	Decrease the inflow rate into the actuator by using an appropriate pump; use a clear command word to facilitate deactivation.	3	2	1	6
	Wear leads to rupture of silicone membrane.	2	4	2	16	Optimize for an elastic, wear-resistant material.	2	3	2	8

Appendix C – Ethics

An ethical and respectful behaviour lies at the heart of any scientific project, especially when it requires the involvement of target users, both for background research and actual testing purposes. For this reason, a watchful eye was always kept for the whole length of the project over any ethical issue that could have risen from our work.

- Respect of data protection and confidentiality represented the standard "modus operandi" when collecting field information about MND progression during the teams visit at Royal London Hospital. Patients were interviewed with the sole scientific purpose of getting an accurate picture of the stages of the disease, to fine tune the technical specifications of the final design to better suit future users. None of the patient's personal information was either used or published in our work.

- A zero-discrimination policy was also adopted when interacting with the clinic's patients: these were interviewed with no regard to sex, age, ethnicity, social background or religion, and the same concept was also applied to the target users of the finished product.

- Patients' wellbeing and mental health was always a major concern: disease's limitations and lack of independence were always addressed in a cautious and respectful way, with the fundamental idea of maximising the patients' strengths and abilities, rather than simply replacing them with an extraneous device. A minimal, sleek design using compact materials was chosen for the final proposed design, with the objective of reducing as much as possible the psychological impact of wearing an exoskeleton.

- Patients' safety and security was also held into high account: despite not being able to actually test and discuss the final product with the users, the team would have carried out all the necessary laboratory tests to ensure the product was completely safe, preventing the patients from facing any form of health hazard.

- Economical ethics were also considered, in line with our key idea of making a product for all and accessible to all: affordable components and a simple design were preferred, making the product's hypothetical market price extremely competitive.

- Respect for colleagues was considered. In terms of group working and given the division of tasks, the team was careful to respect and trust others with their tasks while also giving constructive

Appendix D – Bill of Materials

	Name	Use	Quantity	Price	Supplier	Source
Arm	Acrylic Sheets	Arm Support body + component box	3 x [420x297x3mm] sheets	N/A	University provided	N/A
	Steel Nuts and Bolts	Arm Support joints	5 x M5 + 6 x M4	N/A	University provided	N/A
	Steel Butt Hinge	Arm Support hinge joint	40 x 100mm approx.	N/A	University provided	N/A
	3D Printed Components	Exoskeleton Structure Beam Support and Hinges	N/A	£45.94	University provided	N/A
	Arm Adjustable Strap	Arm Support strap	1 (2pcs)	£8.92	Moarka	https://www.amazon.co.uk/Tennis-Compression-PlayActive-Sports-Guide/dp/B015I2EC9O/ref=sr_1_13
Glove	Wrist Brace Hand Support	Glove adjustable hand strap	1	£12.99	SIZIMA	https://www.amazon.co.uk/gp/product/B07Y37CH3H/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1
	Silicone Tubing	Pump to actuator tubing	2 x [1/8"(3mm) ID X 3/16"(5mm) OD 3.3ft]	£9.58	Ascot City	https://www.amazon.co.uk/gp/product/B07QKPQPP2/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1
	Battery Pack	Power supply for system	1	£48.99	TalentCell	https://www.amazon.co.uk/gp/product/B0713T4XT9/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1
	Raspberry Pi 3B	Microprocessor for system	1	£37.18	Raspberry Pi	https://www.amazon.co.uk/gp/product/B01CD5VC92/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1
	Raspberry Pi Kit	Electrical equipment	1	£21.95	Freenove	https://www.amazon.co.uk/gp/product/B06WP7169Y/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1
	Felt-Making Base Mat	Box foam inner lining	25x25x5cm	£2.12	Knorr Prandell	https://www.amazon.co.uk/Knorr-Prandell-Felt-Making-Black/dp/B0024K1ALC/ref=sr_1_1
	Fingerless Gloves	Glove main body	1	£7.81	Draper	https://www.amazon.co.uk/Draper-14973-Fingerless-Work-Gloves/dp/B01LZQNJXO/ref=sr_1_1
	Elastosil M 4601 A/B	Actuator mould	1kg	Free Sample*	Wacker	https://www.wacker.com/h/en-us/silicone-rubber/room-temperature-curing-silicone-rubber-rtv-2/elastosil-m-4601-ab/p/000018458
	USB Microphone	System voice input	1	£9.85	iGOKU	https://www.amazon.co.uk/dp/B076M4HXFH/ref=cm_sw_r_wa_apap_FbfnwjEAYAwCl
	Air Pump Motor DC 12V	Actuator pump	1	£11.34	Aigend	https://www.amazon.co.uk/Mini-Air-Pump-Motor-Instrument/dp/B0822FFHD9/ref=sr_1_1
	Electric Pump	Actuator pump	1	£50.50	RS Pro	https://uk.rs-online.com/web/p/positive-displacement-pumps/7026894/
	Solenoid Air Valve	Air flow valve	2	£13.99	AOMAG	https://www.amazon.co.uk/Position-Pneumatic-Electric-Solenoid-Valve/dp/B07YXT6FLF/ref=sr_1_3
	Pneumatic Connectors	Valve inlet/outlet connector	1 (10pcs)	£7.89	RuoFeng	https://www.amazon.co.uk/Pneumatic-Connector-Fittings-Industry-Automatic/dp/B07KRSZ4DC/ref=sr_1_1_sspa
	Non Return Valve	One way valve for air flow	2	£8.39	RS Pro	https://uk.rs-online.com/mobile/amp/p/pneumatic-positive-pressure-vacuum-non-return-valve-function-fittings/3670624
	Self Adhesive Velcro Tape	Attach Actuators to Strap	1 (5m)	£7.99	LZHOO	https://www.amazon.co.uk/LZHOO-Adhesive-Double-Sided-Sticky/dp/B07BTG72K3

*First kilogram of Elastosil is free, then £69.98/Kg

Appendix E - Nomenclature

PneuNet (Pneumatic Network): PneuNet is a type of actuator made of several chambers connected by a channel. It is made of elastomer. When air is injected into (pressurized) it bends and generate a force at the tip.

GPIO (General Purpose Input-Output): Pin connecting a microprocessor (Raspberry Pi) to external electronic components (pumps and valves). They can receive signals or output a signal. In this device, the GPIO outputs or not 3.3V.

Hook and Loop: Fasteners, popularly available from the Velcro® Brand, which are made of two strips with opposing structure to be securely attached when brought together, therefore holding the opposing surfaces in place.

Appendix F – Input-Output Code

```python
import argparse
import locale
import logging
import RPi.GPIO as GPIO

from aiy.cloudspeech import CloudSpeechClient

pumpPin = 11    # define pump GPIO pin
valve1Pin = 23  # define first valve pin
valve2Pin = 21  # define second valve pin
ledPin = 29     # define led pin
GPIO.setup(pumpPin, GPIO.OUT)
GPIO.setup(valve1Pin, GPIO.OUT)
GPIO.setup(valve2Pin, GPIO.OUT)
GPIO.setup(ledPin, GPIO.OUT)

def get_hints(language_code):
    if language_code.startswith('en_'):
        return ('open',
                'close',
                'hold',
                'start',
                'shut')
    return None


```

```python
def locale_language():
    language, _ = locale.getdefaultlocale()
    return language


def main():

    while not establishWifi(): # code which establishes wifi with given SSID
        blink(ledPin)

    GPIO.output(ledPin, GPIO.HIGH)

    logging.basicConfig(level=logging.DEBUG)

    parser = argparse.ArgumentParser(description='Assistant service example.')
    parser.add_argument('--language', default=locale_language())
    args = parser.parse_args()

    logging.info('Initializing for language %s...', args.language)
    hints = get_hints(args.language)
    client = CloudSpeechClient()
    while True:
        if hints:
            print("Say something:")
            # logging.info('Say something, e.g. %s.' % ', '.join(hints))
```

```
        else:
            print("Say something:")
            # logging.info('Say something.')
        text = client.recognize(language_code=args.language,
                                hint_phrases=hints)
        if text is None:
            print("You said nothing.")
            # logging.info('You said nothing.')
            continue

        # logging.info('You said: "%s"' % text)
        print("You said: " "%s" % text)
        text = text.lower()
        file = open('textfile.txt', 'w')

        if 'start' in text:
            check = 1
            blink(ledPin)
        if check == 1: # activation of relevant components
            if 'open' in text:
                GPIO.output(valve1Pin, GPIO.HIGH)
                GPIO.output(valve2Pin, GPIO.LOW)
                GPIO.output(pumpPin, GPIO.LOW)
                file.write('open')
```

```
            if 'close' in text:
                GPIO.output(valve1Pin, GPIO.LOW)
                GPIO.output(valve2Pin, GPIO.HIGH)
                GPIO.output(pumpPin, GPIO.HIGH)
                file.write('close')
            if 'hold' in text:
                GPIO.output(valve1Pin, GPIO.LOW)
                GPIO.output(valve2Pin, GPIO.LOW)
                GPIO.output(pumpPin, GPIO.LOW)
                file.write('hold')
        if 'shut' in text:
            check = 0
            blink(ledPin)

def destroy(): # turn off all components
    GPIO.output(ledPin, GPIO.LOW)
    GPIO.output(pumpPin, GPIO.LOW)
    GPIO.output(valve1Pin, GPIO.LOW)
    GPIO.cleanup()


if __name__ == '__main__':
    try:
        main()
    except KeyboardInterrupt:  # Press ctrl-c to end the program.
        destroy()
```