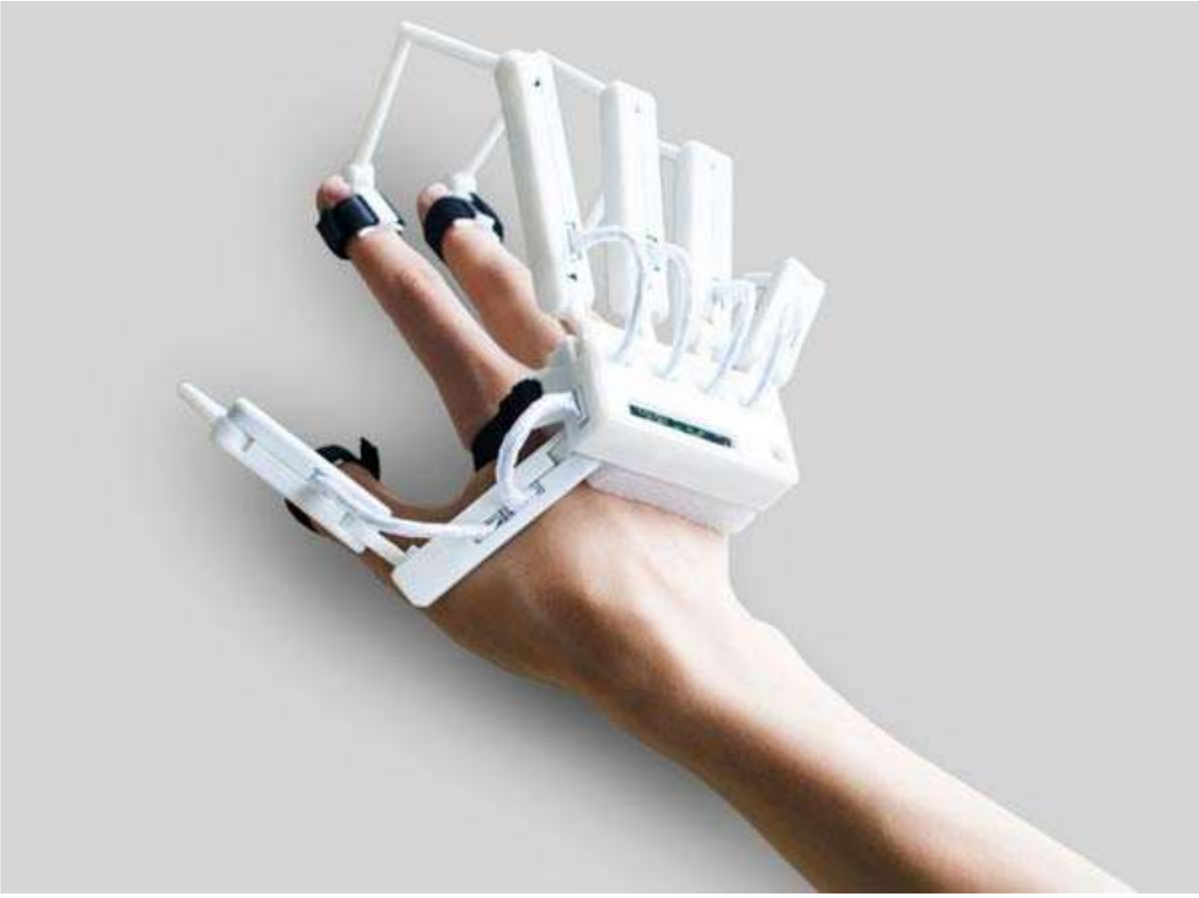
Clutching Glove

Final report Engineering Design (4WBB0)

[25-10-2020]



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Contents

1. Group effectiveness

The team for this project was very diverse in terms of knowledge and experiences. Firstly, our team members mostly followed different majors. The team members came from the following majors respectively: Applied Physics (Yves); Architecture, Urbanism and Building Sciences (Stijn); Chemical Engineering and Chemistry (Thom and Mathy); Computer Science and Engineering (Sam) and Mechanical Engineering (Joep). Due to these different backgrounds, a multidisciplinary team was formed whose members complement each other. For instance, someone from architecture, urbanism and building sciences might not be good in assembling a mechanical device but is good at designing a concept for this, while someone from mechanical engineering will be good at assembling this device due to their knowledge and previous experiences in their major.

The following are the specific abilities and strength were brought to the group by the team members. Most of these strengths come from the different major backgrounds, which further indicates the importance of a multidisciplinary team.

Yves was, due to previous courses taken in the scope of his major, quite acquainted with physical modelling. The use of software with the likes of Origin, Matlab and Mathematica were hence on the table. Physical modelling would become very important in the project as the design was mechanically complex and by 3D printing the parts it was crucial to get precise measurements. In addition to that he is also a quite adequate English speaker and very comfortable presenting projects. This came in use during the intermediate and final presentation.

Mathy's strengths came mostly in the research and organization departments. The designing of a planning and researching of new topics was entirely within his skillset. This was fully used while making a planning with different deadlines for the project.

From the background of Computer Science and Engineering, Sam was familiar with programming languages. This opened the door for programming in Java and Python (with the help of other team members who learned Python during the data analytics course). The theoretical design of circuitry and finite automata/Turing machines was also in his skillset. Because of this background we could integrate an Arduino in our design which would be coded by Sam.

Joep was familiar with components that likely will be integrated in our final product. He was, on top of that, experienced with CAD-design and the physical building of projects. This all stemmed from his experience with other DBL-courses in the major Mechanical Engineering.

From his major, Stijn has experience with drawing out ideas, working in groups and the DBL-structure due to multiple project courses. His experience was capitalized on when making concepts of the design.

Thom has gained experience with the concept of DBL-courses at a DBL elective in year 1 where he developed on of his strong points, writing a report. Another strong point is the physical building of the project. This was used for building the preliminary design together with Stijn.

Besides the strengths of the group, the weaknesses of the members were also mapped out. In terms of individual weaknesses, we collected the following. There were a few people who are not excelling in presenting and there were some members who are not good at coding, then there were also members who were not great at drawing and making concepts. This however would not be a big problem in this group, as for all the individual weaknesses we had someone who was more experienced with that specific skill. That is why there is no real group weakness in this group.

During the project we mostly focused on the strengths of people. Because of the limited time it would not be efficient to learn people how to code or make models by cad-design if they are not experienced in this, or if they have not done it at all. There are however a few things all the members did, like write sections in the report and make design concepts. For some group members, who are for instance not great at clearly writing things in the report or at coming up with original concepts, this would be a good training. During the whole project it was made sure that none of the members did only a certain task but that the tasks were switched.

2. Design goal

The final goal of this project is to produce a wearable, glove-like object that helps people who are physically impaired with the 'gripping' motion of the hand. Also, it provides strength during this procedure of opening and closing the hand. With age, the human body loses a lot of its natural strength. This is most noticeable in the hand and fingers. So, additional strength in this area could be very helpful. The idea originated from the futuristic idea of having unlimited strength. Of course, in a realistic scenario this would, in this point in time, not be possible and maybe also ethically not desirable. Although, the underlying concept of a device giving some additional strength and grip could in certain ways be helpful to, as mentioned, physical impaired people.

According to the NCBI, the amount of distinct loss of muscle mass and strength in individuals over 40 may be as high as 40.9 percent[1]. Apart from the loss of strength and muscle mass there are also several conditions that weaken your grip, such as carpal tunnel syndrome and other conditions that affect your nerves or injuries caused by strain[2]. Sometimes a combination of loss of grip by age and a medical condition occur at the same time as the conditions are more common with people of an older age. Finally, there are people who have lost some or all mobility in their hand as a result of an accident or impairment, for example in extreme cases of ulnar nerve palsy. *'You may lose sensation and have muscle weakness in your hand if you damage your ulnar nerve. This is known as ulnar nerve palsy or ulnar neuropathy. This condition can affect your ability to make fine movements and perform many routine tasks. In severe cases, ulnar nerve palsy can cause muscle wasting, or atrophy, that makes the hand look like a claw. Surgery is sometimes necessary to correct this.'*[3]

These impairments form the base for or final product. We are aiming to give people some extra strength to support basic indoor tasks, without the help of a supervisor. These tasks, such as gripping a cup of tea, picking up a book or open a door, can – with this aid - be done independently, increasing the joy in performing normal everyday tasks without any worry or notice. Ultimately, the aim for this aid is for the user having the convenience of not having to think about what they are doing, when picking up something. Realistically, considering the time frame, budget and the lack of the groups experience in this field, the device would probably not be as sleek and unnoticeable, where the user would forget about wearing the device, but it should fulfil the main goal, which is the extra provided grip and strength.

There were several concepts for a device that would improve this impairment. All concepts came with different challenges, some harder to overcome then others. There were 2 designs that would be the most feasible. One made use of ropes that would close the hand by reeling in the ropes. The main challenges with this design was the location/route of the ropes and the risk of failures with ropes getting stuck. The other design used some sort of exoskeleton to close and the hand. The main challenges of this design where the way of controlling the fingers and size of the external skeleton. Both design where realized in a preliminary mock-up design.

The second device, the one that made use of the exoskeleton, was chosen to be further developed. the preliminary designs are more explicitly shown in chapter 4, about the design concepts, and the requirements and final design concept for the exoskeleton in chapter 3 and 5 respectively. The use of an exoskeleton, in combination with servo's make the glove able to move its fingers, so the hand can be opened and closed.

Pressure sensors make sure the gripping strength does not exceed a certain threshold, a possibility of adding a heat sensor to keep the wearer of the glove safe against mainly too high temperatures, when working with boiling water for instance. Finally, gripping material on the thumb should make the entire system more secure and provide a decent amount of grip. These features lead us to believe that this system is innovative and novel.

Additionally, this design enables us to use the knowledge of our group members to their full potential. We need knowledge from all kinds of fields to bring this project to a satisfactory end; it needs programming, designing, physical modeling and much more. There are also members with experience in working with servo's and Arduino's and in 3D modeling and printing. These experiences are very useful as we intend to make use of Arduino's, servo's and 3D printing.

3. Functional design and solutions

The following is the functional design for our glove. As stated before, the main idea of the glove is to provide extra clutching strength to those who lack it as a result of old age or a physical impairment. To achieve this goal, we have decided upon the following (using the MoSCoW method).

Functional Design

Must:

- Be safe, it should be a safe aid to use daily.
- Be wearable, it must fit on/ around a hand.
- The product must close/ open the hand (Help grab something/keep something gripped/power to improve the strength/could have moving parts).
- Sense hand movement.
- Measure pressure at the fingertips
- Stay within the budget of 70€.
- Have a combination of sensors and actuators.
- Function autonomously or by interaction with the user.
- Have the maximum dimensions: 0.34 x 0.23 x 0.31 $m^{3.}$

Should:

- Be "light", so the person wearing can lift their own hands.
- Should be comfortable.
- Should deliver the force to apply grip to objects.
- Long lifetime, it should not break quickly.
- Give the user increased mobility.
- Be able to cover a hand.
- Cover fingers to the tip.
- It should have two states: tightened and relaxed (reversed force).
- Be flexible, you should be able to move your hand freely whilst wearing the glove.

Could:

- Have a nice design, since it is an item for all day use.
- Sense textures.
- Signal potential dangers.
- Sense heat / temperature.

Won't:

- Supply some type of force counteracting the weight of the, to be lifted, object. (The project is just about the hand and gripping something and not about assisting with lifting objects)

Solution Encyclopedia

The functional design does not stand by itself. Each function should be accompanied by one or multiple solutions, for this purpose we have made the following solution encyclopedia.

Functions	Solutions
Be flexible, you still must move your hand freely	No heavy materials
	Make the glove compact; nothing sticking out
	Elastic material
	Hinges on natural location to incorporate natural movement
	Keep battery's/ heavy components not on the hand but on the wrist
Be safe, it should be a safe aid to use daily	No open wires/connections
	Have a maximum pressure it puts out
	Some form of heat/cold resistance
	Safety release that cuts the motors off
	Maximum speed at which it can close or open
	Protection for when the device overheats
Should be wearable, it must fit on / around a hand	Use of a glove
	Taped around each finger
	All the parts screwed into the hand
	Replace the whole hand
	Multiple segments mimicking the hand phalanx bones (providing flexible movement)
	Replace the bones in the hand
The product must help to close / open the hand (Help grab something / keep something gripped / Power to improve the strength / Could have moving parts)	Motors
	Strings
	Hydraulics
	Magnets on the fingertips and in the hand
	Robot hand that squeezes the hand
	Using a material in the glove that contracts/expands after certain stimuli (heat, light, electricity)
	Makes use of the force
	Use compressed air
Sense hand movement	Make use of a gyroscope
	Use an accelerometer
	Use a proximity sensor or a gravity sensor
	Make use of kinematics or pressure sensor
	Use location sensors
	Sensors that measure the angle of the motor
Measure pressure at the tips	Put pressure sensors in the tips
	Put stress sensors in the tip or the segment put on the fingertip

Be “light”, so the person wearing can lift their own hands	Use as little dense materials as possible
	Use light materials that can withstand strong forces, like carbon nanotubes
	Cover only as much of the hand as is absolutely needed
	Use small batteries to reduce weight
Should be comfortable	Ergonomic design
	Comfortable-feeling materials
	Shouldn’t be too thick as to not trap too much heat
	Incorporate air conditioning and heating
Should deliver the force to apply grip to objects	Use motors which produce enough friction force
	Use hydraulics
	Use a spring mechanism
Long lifetime, it should not break fast	Use sustainable materials
	Well-designed structure that is capable to experience and handle the forces put onto it
	A structure that distributes the force over a larger area
	Make use of titanium or mithril
Be able to cover a hand	A glove
	Rings around the fingers
	Segments
	Prostatic hand over the original hand
Cover fingers to the tip	Design the device in such way that the glove, segments cover at least the tips, if the whole finger isn’t covered
It should have two states: gripped and relaxed	When the motors perform work, the hands close
	When the motors reverse the hand is opened
	If strings are used, and the strings are no longer under tension, the user should be to open their hand on their own
Design, since it is an item for all day use it should look good	Put a layer over the mechanics of the glove (also as protection for the parts)
	Make the device somewhat esthetically pleasing
	Make the system in an existing glove to keep the esthetics
Sense textures	Measuring the friction of the material
	Light scattering/reflecting of the surface giving an idea of the ‘landscape’ of the material
Signal potential dangers	Light emitter
	Vibration motor
	Speaker
	Small shocks
	Heat element that captures the users' interest

	Automatically open hand to release the held object
Sense heat / temperature	Use heat sensors
	To give feedback to the device
	Use a bi-metallic thermostat
	Use a thermistor
	Use a resistive temperature detector
	Use a thermo camera

Table 1: Solution encyclopedia

4. Design concepts

During the designing process, multiple designs came to mind. When it was time for the mock-up design, the team settled on three main ideas, namely, the string concept, the exoskeleton and the additional sensors mockup.

The string concept was based on the idea of using strings attached on one side to the finger and on the other to a motor. The motor would contract the strings, pulling the fingers down in a downwards motion, hence pulling the entire hand down and resulting in a gripping motion. There were however several problems with this idea. Mainly, the strings would have a high chance of getting entangled with each other or some other component. We thought about counteracting this with the use of a channel through which we could lead the strings but concluded that this would result in a loss of pulling power due to a higher amount of friction between the ropes and the gloves and channels, hence making it unsuitable for our project. Moreover, pulling the thumb with a string in a perpendicular fashion resulting in an unnecessarily high complexity in the design. Because of these faults, we decided to eliminate the string concept.

The string concept designs:

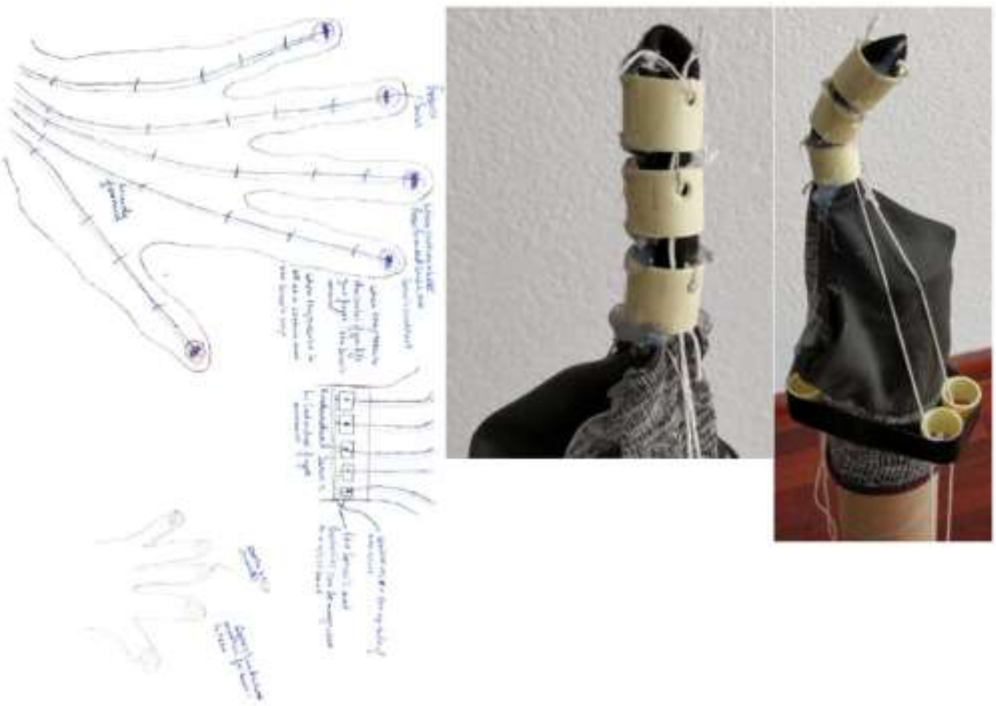

Figure 1: String concept

Our second idea was to make use of an external gantry to support the movement of the hand. i.e. an exoskeleton. The exoskeleton design consists of a glove through which the end user connects to the exoskeleton, which lays on top of the hand. By placing the fingers inside of the glove, they contact small cylindrical tubes which are attached to a motorized hinging mechanism. These tubes will be able to force the hand of the user into a gripping motion.

The glove will contain 5 of these cylindrical tubes, one for each finger. The movement of the four 'main' fingers will be dealt with by 2 servos. The servos are connected to a bar which makes use of the leverage phenomenon. This bar is attached to the cylindrical tubes.

The movement of the thumb is dealt with in a similar fashion, of course in the correct direction (somewhat perpendicular to the other fingers). It will have its own servo and its own hinging mechanism, to ensure it can move independently from the other fingers.

The interaction with the user is dealt with via pressure sensors that detect movement in the hand of the user. The pressure sensors in the fingertips also ensure that fragile object can also be gripped without breaking by determining a pressure at which the servos should stop. The information will be processed by an Arduino located at the forearm of the user.

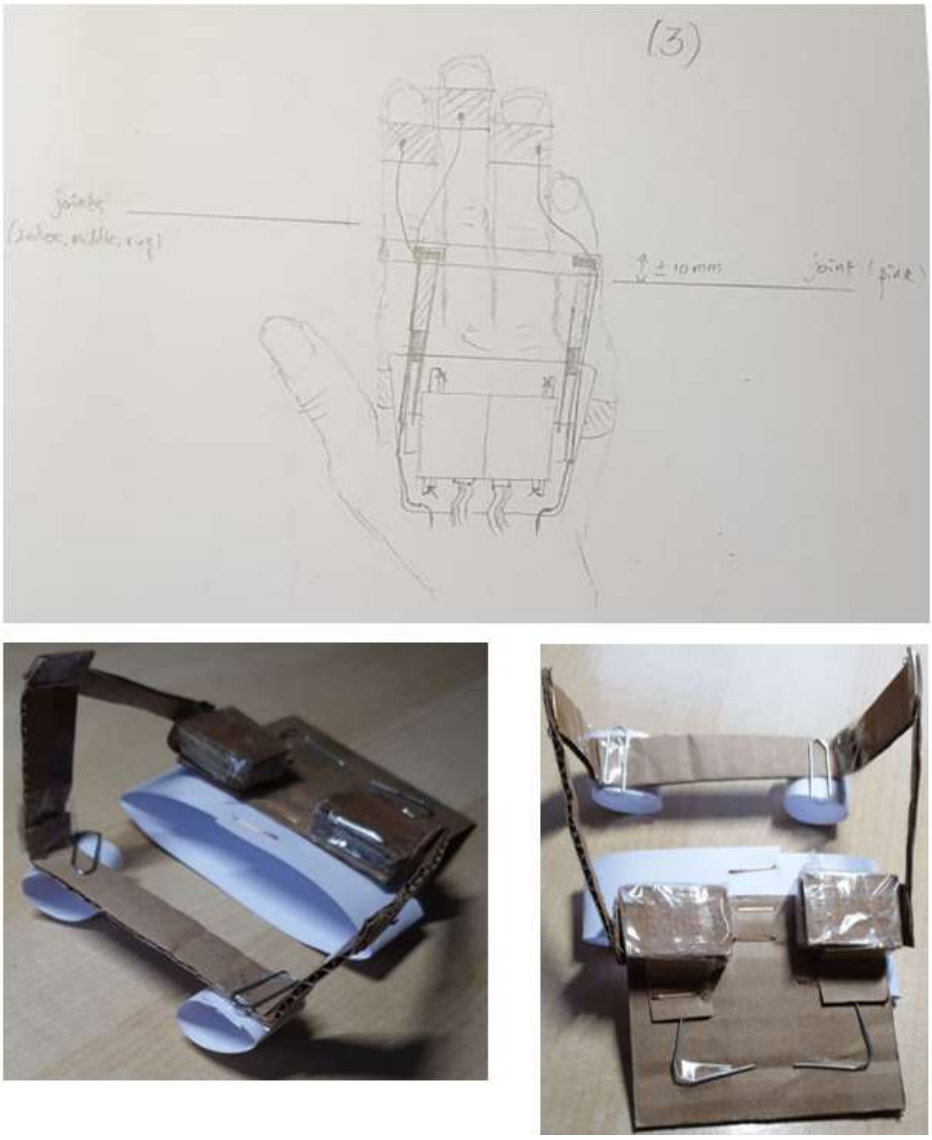

Figure 2: Exoskeleton concept design

The third idea is entirely dependent on the idea of the exoskeleton. It uses the same basic ideas but incorporates more fail safes and sensors. We hence dubbed it the ‘additional sensors' concept. The general idea is as follows:

We take everything as described in the exoskeleton concept. To ensure that a user does not burn his/her hands while using our glove, make use of a heat sensor located near the palm of the glove. The reason we opted for a heat sensor is that the glove is designed for in-house use, like cooking or grabbing glasses/mugs. Because of the thick structure of a glove, and the fact that it is designed for people that are already suffering of an impairment in their hands, it is entirely within the realm of possibility that the user does not notice if it is grabbing an object which exceeds the maximum temperature. Imagine if the glove did not detect this, and the user grabs such an object. The glove contracts and keeps the hand of the user pressed firmly against the burning surface. This can have catastrophic events., albeit with a small chance of transpiring. Hence, we opted to place a heat sensor near the palm of the glove, which first checks if the temperature of the object is acceptable before engaging in the gripping motion.

A second sensor we considered adding was a texture sensor. As I hinted at in the last paragraph, the target demographic for this project is those with an impairment concerning their hands. The loss of feeling is a common one, especially when you add to that the fact that the user will be wearing a thick glove over their fingers. We imagined giving some of these feelings back by using texture sensors in the tip of the fingers.

Additional sensors concept:

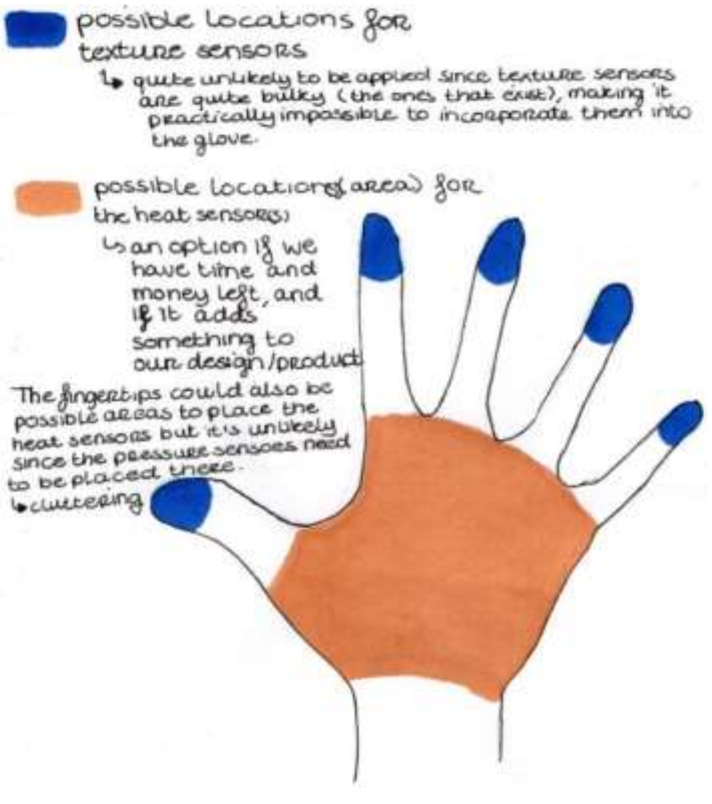

Figure 3: Additional sensor concept

As described in the image above, this idea is somewhat ambitious. The texture sensors are extremely bulky and unwieldy, which goes against our product specifications. Hence, we decided against this idea. Moreover, we decided to first focus on functionality of the actual clutching before implementing a failsafe for unlikely events, so the heat sensor was made a ‘could', in case we have time and money left. All the above considered, we decided to take the normal exoskeleton concept as our final design.

5. Final design concept

The final design of our project directly follows from the exoskeleton mockup described above.

It consists of 3 main parts; they will be described separately.

Arguably the most important part of the glove is the exoskeleton. It consists of hinges connected to the fingers at two places: the fingertips and the lower part of the finger. Using leverage, we can ensure that the gripping motion goes naturally, instead of being distributed evenly along the finger. These hinges will be connected to two servos, one on either side. The movement of the thumb will be handled along the same line of thought, with some exceptions, however. The thumb will have to move in a somewhat perpendicular line to the other fingers, as to ensure a good clutching motion. It will get its own hinging system that only connects at one spot on the base, instead of two. It will also contain only one servo, but for one finger, this is sufficient.

The second main part is the Arduino and the sensors. Positioned on the forearm, one will find the Arduino. This will be the brain of our glove. It is connected via cables to the servos and all the sensors located inside the glove. It receives data from these sensors and makes calculations with said data to eventually control the device with the use of all this data received from the sensors. Here follows a brief overview of all the sensors, their location and use:

- The main sensors are in the tips of the glove, these are the pressure sensors. They will measure the amount of pressure exerted by the glove on the object. With the calculating power of the Arduino, these will ensure that even fragile objects can be picked up and will not break by applying too much pressure. This also acts as a failsafe.
- Next to being able to limit the amount of pressure applied to the object from a perspective of safekeeping, the pressure sensors will also act as an initializer for the movement. When the user gently presses on these pressure pads, the servos will activate.
- The glove should also contain a heat sensor to send a warning to the user when gripping a hot object. We do not want the end user to burn him/herself whilst using our glove. This sensor hence also acts as a failsafe and as a protection for the glove itself.

Lastly, we have the glove itself. It will be comfortable, compact and sustainable, making the device easy to use, and cover the hand to the tip. We also want to make the device lightweight to allow more mobility, this is done by making use of light and sustainable materials. By using a soft material around the hand and the fingers the device is made more comfortable, using for instance a soft glove. This glove will be directly on your hand, there will also be a glove on the outside. This glove will hide all the sensors and wires and have a material on the inside of the hand that improves the grip.

The preliminary design is bulkier than we want our final product to be. To decrease the bulkiness, whilst keeping the design functional, physical modelling was performed to find a more appropriate length of the different beams.

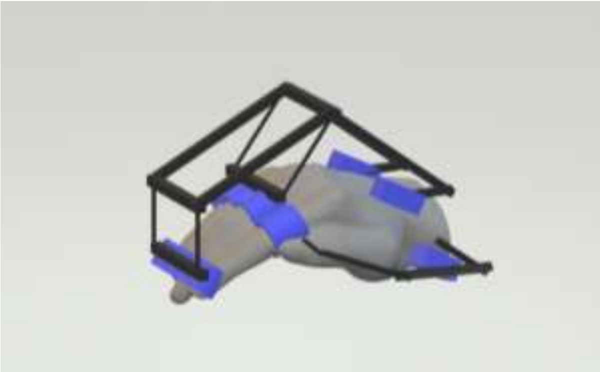

Figure 5: Model of the prototype

Figure 4: Prototype

6. Technical specification

During the concept phase several functional specifications were listed; while these specifications were difficult to assign values to, the decision was made to develop the technical specifications during the realization phase, working within the limits of the budget.

The functional specifications to which values could be assigned were:

Must

- Be wearable, it must fit on/ around a hand.
- The product must close/ open the hand (Help grab something/keep something gripped/power to improve the strength/could have moving parts).
- Measure pressure at the fingertips

Should

- Be "light", so the person wearing can lift their own hands.
- Deliver the force to apply grip to objects.
- Long lifetime, it should not break quickly.
- Be able to cover a hand.
- Cover fingers to the tip.

The technical specifications of our final design are described in the following table:

Dimension	Value	Details
Clutching torque	2.5kg · cm (4.8V)	3x S92R servo
Voltage battery	9V	Aerocell battery
Mass objects	1-2 kilos	Maximal mass of the objects which can be held by the glove
Length	24 cm	From the tip of the middle finger to the wrist
Length (2)	17,5 cm	Length of the plate mounted on the forearm.
Width	17	Width of the glove (in the 'open' state)
Width (2)	6,8 cm	Width of the plate
Height	6 cm	In the 'open' state
Height (2)	3 / 4 cm	In the 'closed' state
Max. temperature	49°C	[4] Heat deflection temperature PLA
Min. temperature	-20°C	[5] Minimal operating temperature 9V battery

Water resistant	No	Only the fingers of the glove can be considered splash proof
Estimated lifetime	2-3 hours	Refers to active usage (estimate).
Estimated battery lifetime	12 hours	[5]

Table 2: Technical specifications

7. Detailing

Modelling and calculations

The following functional specifications were relevant for the modelling of the design: The product must help to close / open the hand and be flexible. The process of modelling required several iterations concerning the rods, which would be structured in such a way that the hand, on which the model is located, would follow its natural movement of closing and opening as similarly as possible.

Several constraints which applied to the model were the use of two servos and the placement of the connection points between the rods and the fingers in the middle of the fingers, this gave a more discrete basis for the model. The constraint of two servos, because of budget, did not allow the fingers to be stimulated separately, greatly reducing the flexibility of the design.

First the movement of the upper four fingers was modelled, because these display approximately the same movement, afterwards the thumb was modelled separately. By treating the hand and its joints as a line with several rotation points, the parameters could be assigned more easily. While the hand must be able to close completely the model took in to account the maximal angle between the different finger segments.

A distinction is made between two states: The open/relaxed state and the closed/tightened state. While the hand consists of several joints, each rotation of a joint will be stimulated by a combination of rods emulating the natural rotation around that point; these rods are also depicted as abstract lines.

After a few iterations the following model for the upper four fingers was agreed upon:

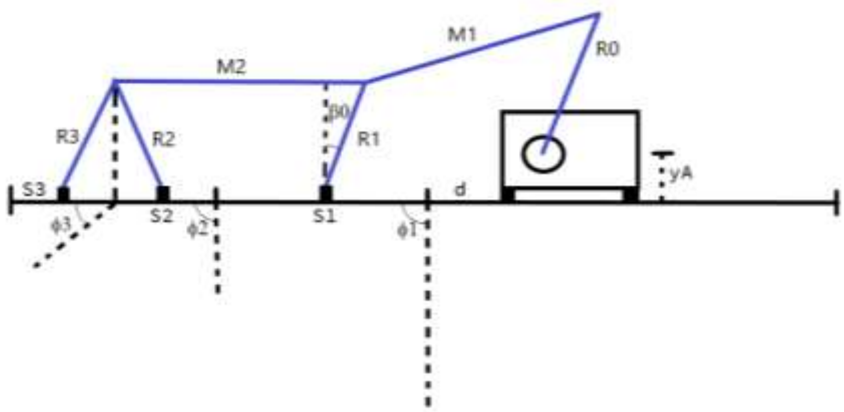

Figure 6: Physical model of device

In which R_0, R_1, R_2, R_3, M_1 and M_2 are rods interconnected with bolts and with R_1, R_2 and R_3 connected to the finger and R_0 connected to the servo; all rods are connected such that they are able to rotate at their connection points. The finger segments are denoted by S_1, S_2 and S_3. The angles between the different finger segment are denoted as φ_1, φ_2 and φ_3, which are at the tightened state approximately 90°, 90° and 45° respectively. θ_0 is the angle between R_1 and the normal of the finger segment S_1. d is the distance from the knuckle to the rotation point of the servo and y_A is the vertical distance from the hand to the servo rotation point.

Ultimately this model was chosen while it emulated the hand movement the best. First when the model shifts to a tightened state R_0 turns around the rotation point of the servo; this initially applies a force directed to the left, which pushes R_2 and R_3 over an angle φ_2, the servo also applies an increasing force downwards, which causes the angle φ_1 also to shift to 90°.

When an object is clutched and S_2 touches the object the force of the servo is redirected to the segment S_3, because of its pyramid structure, this allows the finger tips to wrap around the object and measure the pressure applied by the servo with the use of sensors.

For S_3 to make an angle φ_3, M_2 had to be shifted approximately $R_2\varphi_3$. For S_2 to make an angle φ_2 w.r.t S_1, M_2 had to translated by rotating R_1 around its pivot point over an angle $\Delta\beta$ and taking into account the additional translation to rotate S_3 w.r.t S_2. This gave a change in angle between R_1 and the normal of S_1:

$$\Delta\beta = arcsin\left(\frac{1}{R_1}\sqrt{(R_1 sin(\beta_0) + S_3)^2 + (R_1 cos(\beta_0) + y_D)^2} - \sqrt{(R_1 sin(\beta_0) + S_3)^2 + (R_1 cos(\beta_0) - y_D)^2} - \frac{1}{2}\phi_3 R_3\right)$$

with $y_D = \sqrt{(R_2)^2 - \left(\frac{1}{2}S_2\right)^2}$ and $S_2 = S_3$. This gave a degree of freedom in choosing the initial angle β_0, although the angle should not allow the rods to intercept with the hand.

The lengths M_1 and R_0 were chosen as to distribute the force of the servo evenly downwards and to the left, with R_0 pointing vertically upwards in the open/relaxed state. While only two servos were available, R_0 had to have a fixed length, varying the lengths of M_1 according to the lengths of the fingers.

The thumb, only having two joints and applying the most force, was given the third servo. The tightening of the thumb was fairly similar to that of a normal finger, although one joint was left out. The final design of the thumb exoskeleton was subsequently agreed upon.

In which R_5 and R_6 are the rods connecting the fingers to M_3 which is connected to R_4 without a pivot point; R_4 is connected with a pivot point to R_0', which is connected to the servo. M_3 and R_4 make an angle κ as to prevent the rods intercepting with the hand. R_5 and R_6 display the same pyramid mechanism discussed earlier. M_3 was chosen to be initially parallel to the finger in the open state with a maximal height of y_G (See appendix A for all calculated values) .

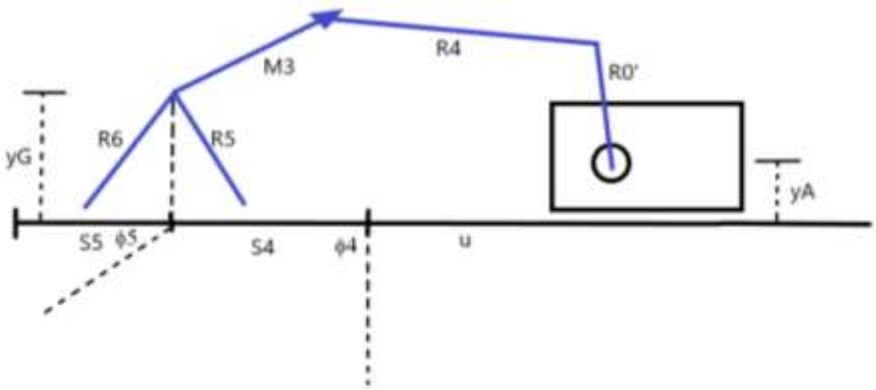

Figure 7: Physical model of device at the thumb

Programming

The programming of the Arduino was done with the use of the stand-alone Arduino Integrated Development Environment (henceforth simply the IDE). This IDE is a mixed bag of different programming languages and styles. The environment itself is written and operates in the Java language, whilst the code (called 'sketches') written and run on the Arduino is a subset (read; 'dialect') of the C/C++ library. The board we have chosen for this project is the Arduino Uno rev 3, which uses the ATmego328P microcontroller. This microcontroller is based on the Advanced RISC (Reduced Instruction Set Computer) architecture. This was a positive for the project, since the knowledge about the ARM architecture was readily know in the group. This meant that the programming and using of pins/registers went with adequate speed. Below is a picture of the basic data path found in an ARM processor (taken from the slides of the course 2IC30 – Computer Systems).

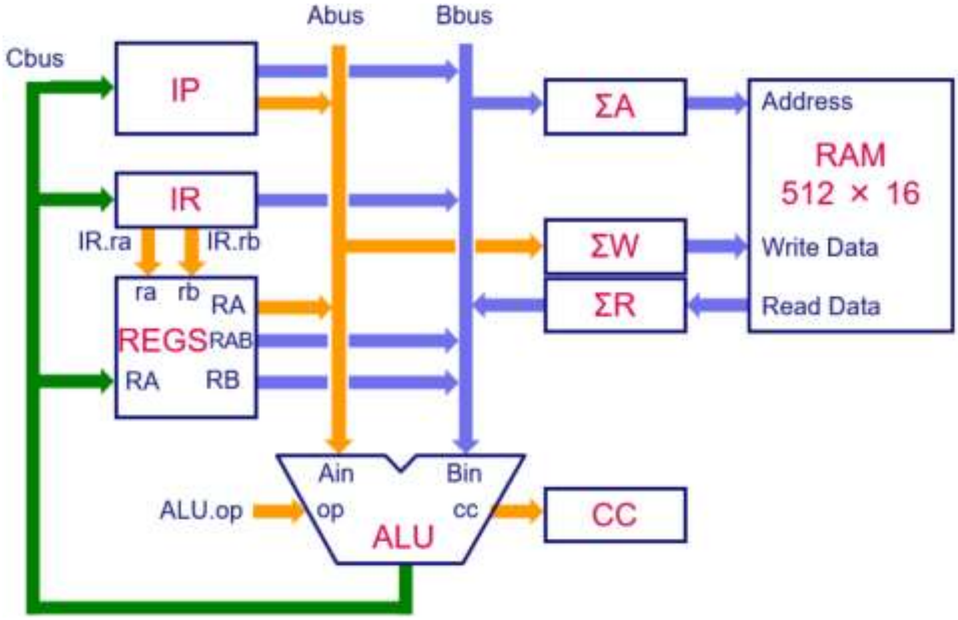

Figure 8: Data path ARM processor

NOTE: this image is extremely abstract and simplified, none the less it can be of great use.

The programming will be done via the spiral method, meaning that it will consists of many iterations. After each iteration (consisting of approximately four parts) it can be decided if the delivered code is satisfactory, or if a new iteration cycle is needed. This ensures that the project develops iteratively, as opposed to the waterfall method. By working iteratively, we will ensure that we are in the possession of working code almost immediately. Hence, if in a further iteration we get stuck or run out of time, the core of the code is functional. A negative of this method is that we will see a diminishing return on investment the more iterations we pursue, I.e. the first iteration will yield the most results when compared to alter iterations. This means we must decide to which level of perfection the code should function.

8. Realization

Bill of materials

Name	Type	Brand	Supplier	Amount	Price per part	Total price (all parts)
UNO rev 3	Arduino	Arduino	Amazon	1	€ 21	€ 21
Taiwan alpha membraan druksensor	Pressure sensor	Model: MB060-N-221-A04	Tinytronics.nl	2	€ 5	€ 10
SG92R Mini Servo	Servo motor		Tinytronics.nl	3	€ 4.50	€ 13.50
Power source - Arduino	9V battery box		Tinytronics.nl	1	€ 3	€ 3
9-volt battery	9-volt battery		Lidl	1	€ 2	€ 2
Dupont cables	10 cm		Bol.com	40		€ 4
(Inner) Glove	Heat resistant glove	Max Pro	Haarimport.nl	1	€ 4.95	€ 4.95
Exoskeleton (3D printing)	Further information in "Plan for production"			1	€ 6	€ 6
Varia: -Aluminum plate -Wires -Outer glove -Velcro						€ 7
					Final expenditure	**€71.45**

Table 3: Bill of materials

Varia include miscellaneous such as glue, wiring, aluminum plates, nuts and bolts. We decided to put these under varia because of the availability around the house and the lack of a substantial price tag.

Plan for production

The exoskeleton was 3D-printed. The material used for printing is called tough PLA. A (Ultimaker) printer was used to print the parts. This was a process of 17 hours and 43 minutes. An infill of 70% is used with a precision of 0.1 mm. The costs of the material used is 5.58m/44 grams of though PLA which costed €2.35 and 2.71m/21 grams of PVA which costed €2.37. The amount in the Bill is higher due to a first test print and some costs at the company that we visited to make the 3d prints.

The assembly drawing

The assembly drawing consists of three parts: a conceptual drawing showcasing how our gloves is supposed to look after reiteration and some additional information to clarify the drawing, 2D drawing of the exoskeleton with all measurements noted per rod and finally is simplified drawing of a servo accompanied with measurements.

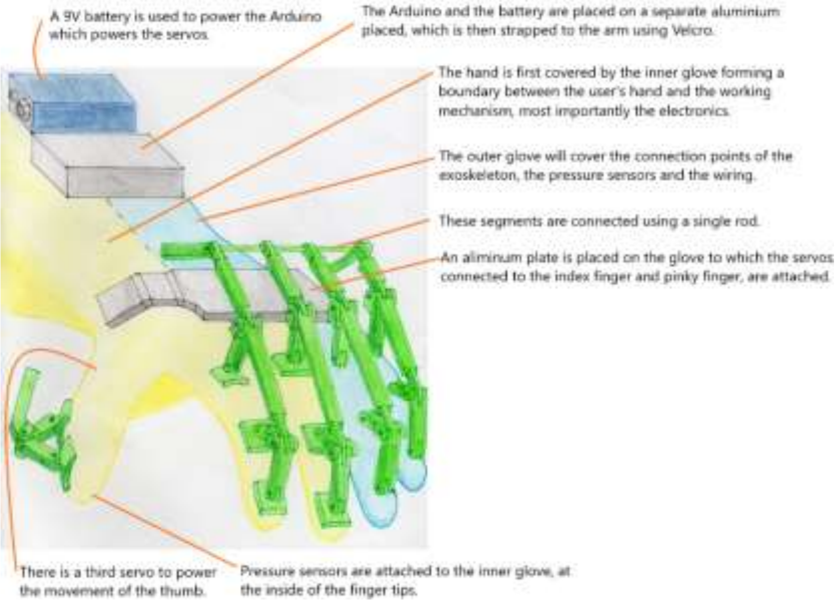

Figure 9: Assembly drawing

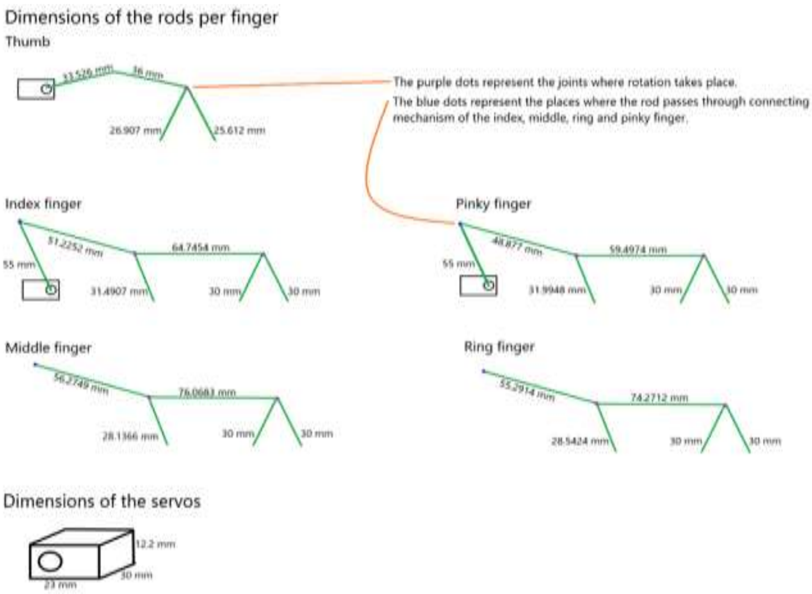

Figure 10: Detailed drawing of different parts

The preliminary tests performed to make sure the individual components performed as expected were the following:

- Simple servo movement.
- Complex servo movement.
- Simple pressure reading.
- Complex pressure reading.
- Completed breadboard test.
- 9V battery test.

As can be deduced from the name of the final preliminary test, all these tests were performed using an 840-pin breadboard. 10cm male to male Dupont connectors were used to make connections between the components, breadboard and Arduino. I will describe each individual test in sufficient detail.

Simple servo movement

The simple servo movement test was designed to ensure that the servos received were functioning. The goal of this test was to make the servo start at an θ of 0 degrees, wait half a second, move to a θ of 180 degrees, and revert. The test was performed using the following electrical circuit, where 'S' stands for the servo.

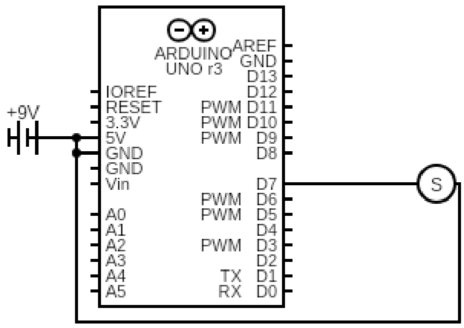

Figure 11: Simple servo movement

NOTE: each servo was tested both individually and in a group of three using this circuit. Moreover, this image shows the battery and servo being connected directly to the Arduino, as described before this is not the case as we made use of a breadboard.

Complex servo movement

The complex servo movement test is much the same as the simple servo test. It was meant to ensure that the servos were up to the task of reacting quickly to inputs given by the Arduino. Just as in the simple servo movement test, the servo starts at a θ of 0 degrees. It does however not wait half a second before moving again. After the θ of 0 degrees has been reached, a for-loop springs into action, increasing the angle of the servo by 1 degree every 10 milliseconds. After a θ of 180 degrees has been reached it immediately moves back to a θ of 90 degrees, before climbing back to 180 again.

This test makes use of the same circuitry as the simple servo movement.

Simple pressure reading

The goal of this test was twofold. Mainly, it was to make sure that the FSR (Force Sensitive Resistor) pressure sensor was operational. Secondly it served to get a grasp on the threshold value for the activation on the glove. Since these sensors will be used to activate the sensors, we need to define a threshold value according to the values it outputs. The test resulted in an interval [0;1000]. It was conducted according to the following circuitry:

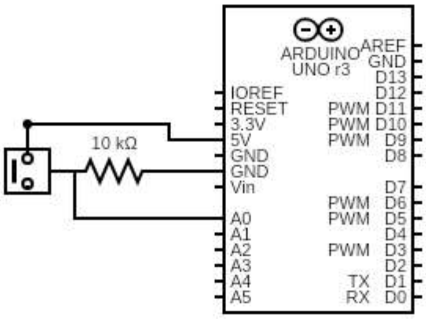

Figure 12: Simple pressure reading

Complex pressure reading

This test was to make sure that the two sensors could operate in harmony. They were both connected via a resistor to the Arduino, which takes the average of both readings and outputs this to the serial console. Other methods of interpolation could be used for these readings, however. Think of assigning a higher coefficient to the sensor connected to the thumb for example, if it turns out that the thumb is of greater significance in the activation of the glove. The test was conducted using the following electrical circuitry.

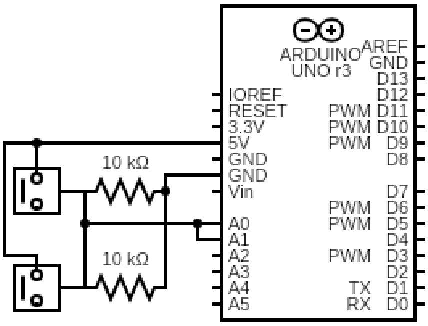

Figure 13: Complex pressure reading

Completed breadboard test

The completed breadboard test is the combination and cultivation of all the afore mentioned test, it keeps in mind every single function the Arduino and all the other components need to perform. It was performed using the following circuitry.

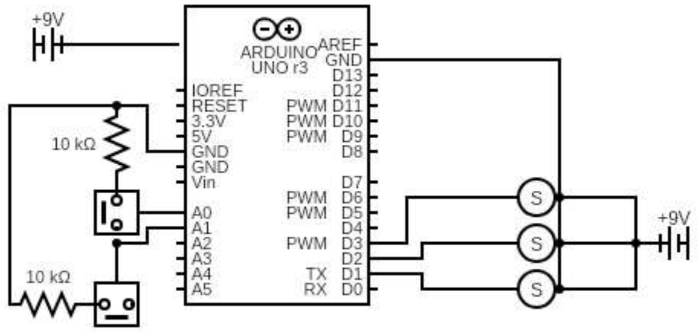

Figure 14: Complete breadboard test

9V battery test

The 9V battery test is in essence the same as the completed breadboard test, the only difference being that a battery now powered the components, instead of the computer via USB. Note that in previous sections the battery is sometimes also included in the circuit diagram. This was done since the batteries were connected during these stages, but not necessarily used. In the 9V test, the Arduino + components ran entirely independently of a computer.

The assembly of the glove was done according to the following scheme.

1. Construct the exoskeleton
2. Construct the plate containing the servos
3. Construct the plate containing the Arduino and battery
4. Attach the exoskeleton to the glove
5. Attach the wiring

We will discuss the process of each of these sub-tasks here. NOTE: whilst we performed these subtasks mostly in the order described here, tasks 1 and 2 were worked on simultaneously.

Constructing the exoskeleton

The exoskeleton consisted of individual 3D printed parts. These parts needed to be sanded down, as to assure a good circular motion, this is of course of vital importance. We used 400 grit sandpaper to accomplish this. The sanding took a significant amount of time, as we needed to make sure not to damage the hinging mechanism or scrape off too much material. After the sanding was finished, each part had to be ordered. All the parts were put together in a bag, but there were small differences between the parts designed for each finger. Hence, we needed to sort this out.

After the pieces were ordered by size / finger, the assembly could begin. Each connection point needed an M3 Philips head bolt, and an accompanying m3 lock nut. The lock nuts were chosen as to not inhibiting the motion. Each individual ‘finger’ was connected using a rod with a lock nut constructing, making sure that movement was allowed whilst not flexing too much.

Constructing the plate containing the servos

The plate on which the servos are mounted, henceforth called the handguard, was constructed out of 1-millimeter thick aluminum. This aluminum was cut to the appropriate size, namely 10 cm. Because the handguard rested on the hand, a few things needed to be done to ensure comfort and safety of the end-user. Firstly, from the perspective of comfort, the aluminum was bended such that it followed the natural curvature of a human hand. Even though this was an ever so slight bend, it made a huge difference when attached. Secondly, the freshly cut aluminum was extremely sharp. This would endanger the hand of the user, as he / she now had to potential to cut him/herself on our product. This was resolved by meticulously sanding down every edge, and rounding off where necessary, to ensure no sharp edges remained.

The servos themselves came with two holes on either side meant for attaching it to a surface. By bending a piece of aluminum in a 90-degree angle, cutting out a hole in the top part to accommodate the servo and tapping the metal on either side, we made a strong and reliable casing for the servo. The bottom of this piece of aluminum was also tapped, providing a way to attach it to the handguard.

The servo for the thumb needed to be attached at an angle, compared to the main handguard. To achieve this, a new piece of aluminum was bended to the correct angle and attached to the handguard with the use of rivets.

Constructing the plate containing the Arduino and the battery

The plate on which the Arduino is mounted is also made from aluminum. This piece was however significantly larger than the afore mentioned handguard. It also rests on the arm of the end user, once more providing us with the challenges of comfort and safety. From the perspective of safety, every edge was sanded and rounded as discussed before. To make the plate comfortable, we bended it once more, this time to follow roughly the same curvature as a human arm.

The Arduino was attached, using friction, to a plastic ventilated bottom plate. This plastic plate contained multiple mounting places for screws, making it the perfect way to securely attach the Arduino to the plate. Both the plastic plate and the piece of aluminum were tapped and threated and screwed together. The bottom part of these screws (which protruded from the bottom of the aluminum plate, piercing the user's skin when used in this configuration), were removed with the use of an eccentric sander.

Next to the Arduino, this plate also contained the 9V battery. Since the battery had to be easily removed and replaced in case it was empty, we decided to construct a small plateau on top of the plate, on which the battery holder was attached using a hook-and-loop fastener (more specifically Velcro). This plateau was attached to the plate using rivets.

Attach the exoskeleton to the glove

This was the most tedious part of the whole assembly. To attach the exoskeleton to the glove we needed to glue down the attachment points to the inner glove, put the outer glove over it and cut holes in it so that the attachment points can protrude. Afterwards we could attach each individual finger to its designated location and connect them with the rod described above.

At this point in time, we were getting tired and made a few mistakes. Firstly, we had readily attached to attachment points to the exoskeleton, meaning we had to remove them. This not only costed us time, but also put unnecessary stress on the components. Moreover, we attached the exoskeleton in the wrong order, left-to-right instead of right-to-left, meaning the ring finger was on the location of the index finger. This was mostly due to the fact that we are all right-handed, making an exoskeleton for a left hand. This once more costed us a lot of time and put stress on the components.

Attach the wiring

The final part of the construction of our project was to attach all the wiring. To assure an easy connection between the servos and pressure sensors and the Arduino, we used male to male Dupont connectors, with one end stripped. To provide power to the servos, the 5V output of the Arduino was used. The Dupont connector was soldered to three other connectors, each of which provides power to one of the Servos (these cables were color coded red). Along the same line of thought, three connectors were soldered to one of the ground pins on the Arduino (these cables were color coded black). The data cables for each servo, color coded orange, were 10cm Dupont cables, connected to digital pins 3, 5 and 6 respectively.

The pressure sensors were stripped down, as to expose the metal to which we could solder our wiring. Each of the two pressure sensors needed two cables, data and ground. These cables needed to be longer than 10cm, hence we stripped down some old wiring. The data wires, color coded purple/brown, were attached to analog pins 0 and 1 respectively. The ground wires, color coded black, were attached via a 10 kilo-ohm resistor to a separate ground pin on the Arduino. The wiring for the servos is exposed on top of the glove, this was done to assure easy access in case of needed repairs. The wiring for the pressure sensors goes through the glove. In the picture below you can see the whole device.

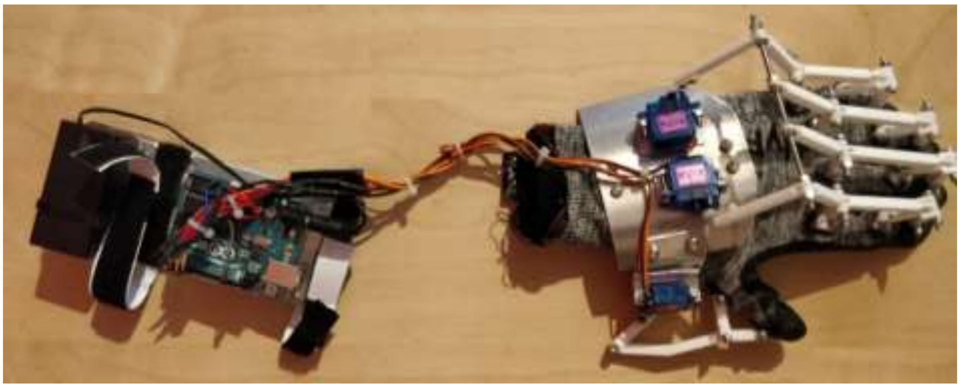

Figure 15: Assembled device

9. Test plan and results

First the different parts of the glove were tested individually to see if there are faults in individual components. It is better to do this before putting the device together because it will be harder to identify the problem on a complete design. The results of these tests are described above.

Now it has become clear that the individual components are working as intended, the entire device can be tested. Before the more specific capabilities of the device will be tested, there will first be some basic tests to see if the device complies to the specifications that are decided to be a 'must' in the MoSCoW ordering. The device must fit on the hand, the device must open and close and it must do so on the movement of your hand, the pressure sensors have to read the pressure put out by your fingers and relate this to the servos. This can be seen working in the presentation.

Testing if the device is safe is more complicated, initially it will be tested if there are appearing any dangerous scenarios with the basic opening and closing of the hand, like wires that become entangled or servo's that behave not in the way intended and other dangers visible by the eye. In a later stage of testing it will be become clear if there are more dangerous situations, when picking up items for instance. Concerning this, the only clear danger is the non-waterproof nature of the design. The Arduino is mounted on an aluminum plate without any further coverage, this leaves it open to water damage. The cables are however protected by the use of both duct tape and heat shrink tubing.

The flexibility of the device should also be tested. As it is a ‘should' on the MoSCoW priority list it is not something that is an absolute necessity, however it should be tested to see if and how flexible the device is. The flexibility of the device can be tested by moving your fingers in the horizontal direction, as the device is not designed to be flexible it will show how much room there is to move your fingers. This test did indeed show the expected results. When the servos are turned off, which is of vital essence to the free movement of the fingers, horizontal movement is severely restricted. This is a result of the connecting rod, preventing the independent movement of fingers. The vertical is however somewhat more forgiving, whilst the movement is still compromised, it is not nearly as bad as the horizontal direction, meaning fingers are free to move up and down in a somewhat independent manner.

Now that we confirmed that the device has the basic functions, more specific capabilities can be tested.

First, we want to test how much weight the device can lift. We will do this by picking up different items of increasing weight from 0,5 to 5 kilo’s or until the item can’t be lifted. For this test, the following object were lifted without a problem: a can of soda, an empty glass, a full glass, a full water bottle and an empty bag. The hand did have some problems with the filled bag, which had to do with the strain being put on the servos, hence we decided to abort this test as to prevent breaking the device. Hence the goal of 5 kilo’s was somewhat ambitious, and the glove is more suited for cutlery and light household tasks, say 1-2 kilos.

The second test will be a stress test to see how much pressure is being applied by the servos. This will be tested by picking up different objects that can break under certain pressures. We will test grabbing a glass, a paper cup, an egg and an orange. This test will help to see if the servos are adjusted properly, or that they need to apply less or more pressure. This test was, in hindsight, of a lesser importance. The clutching glove does not provide enough power to break fragile objects.

Then we will need to test picking up items with different shapes. This test will show, together with the previous two tests, what objects the device will be able to pick up. The objects we will test picking up are the following: a mug, first by the base and then by the ear, a rectangular shaped object like a book, a larger round shaped object like a ball, a small object like a pen or even smaller a paperclip and the railing of a staircase. The results from this test showed as a general rule that larger objects were easier to grip, whilst smaller objects presented a challenge. This is a result of the fact that the glove does not close entirely, but more akin to 70 percent. This means that small objects such as a pen or the ear of a cup can slip through the gap.

Concluding, the tests showed that the clutching glove’s main use is for somewhat larger, lighter household objects, say a water bottle or a mug. Whilst smaller and / or heavier objects can be gripped, they present the unique challenges of making sure to not let the object slip through the gap between the fingers and the hand, and not putting too much strain on the servos. Hence, we recommend to not use the glove for these kinds of object.

10. Design evaluation

Design

Our deign accomplishes the goal we had, to an extent, giving people who lost force in their hands hold everyday objects. Due to budget limitations we could only make it possible that the glove closes that far so that the user can hold “bigger” objects, like glasses, bottles and so on. However, it was not possible to make glove close to an extent that it could help holding “smaller” objects like pencils.

The design could improve in a next iteration, by making the inner and outer glove separable. If they are separable, one could get out the inner glove, which has been collecting sweat during the time of use, and then have it washed. This is quite important, since after a long time of use the glove will have collected a substantial amount of sweat, which comes with unpleasant odors. This can lead to the user wearing the glove less, when they hindered by the smell.

The glove could also improve by using rechargeable batteries, instead of the 9V battery we now use. This makes it more sustainable, since you do not have to switch batteries after repeated use. To make the recharging easier for the user, the rechargeable battery should be chosen and implemented in such a way that the battery could be plugged in, without removing it from the glove.

Planning

There are multiple places for improvement in our planning. One improvement is that actions should have been taken quicker at different points of the process.

This includes the decision what functional was going to be worked out into a product, and the ordering of the components. Later steps of the process were already pushed back by the late decision on which prototype to work out, and they were pushed back further due to “late” ordering.

In the end this all added up to the final device being built in the second-last week and the final adjustments being made shortly before the final presentation.

So, in short, our design process could be improved by taking certain actions quicker, which would give us the opportunity to follow the basis out the planning set out by the course more closely, which would have given us more time in the end during the assembly and (final) testing of the device.

Modelling

During the modelling phase a balance had to be found between the mobility and the force applied by the device; larger servos would result in a tighter grip but would make the design bulkier and heavier. A balance also had to be found between the flexibility of the device and budget constraints; while initially it was proposed to make it possible to move every finger separately, it was later agreed upon that this would make the glove to bulky and would result in the project going over budget; that is why the decision was made to use only three servos as to balance these factors out.

Ultimately the device was tested, which revealed several vital errors in the modelling of the exoskeleton, while the glove did close, it did not close completely. The factors which could have influenced this deficiency:

- The height between the connection points (between the rods and the finger segments) and the finger segments was not taken into account. This caused the exoskeleton to be shorter than it ultimately should be, while it had to wrap around a larger distance than was assumed.

- The modelling of the thumb was done too rapidly without checking if it would actually work, this problem was only noticed in the building process, causing time delay.
- The communication of the lengths of the segments was open for interpretation, while the distance between the rotation points was taken as the whole length of the segments, this caused all 3D printed material to be ±2mm shorter than intended.

The first problem could have been overcome by making the model higher, although this would go at the cost of the mobility. Many problems are attributed to the abstractions made in the model; if more time was taken to intuitively observe the model, the process of modelling might have gone better. All with all the design did partially close, allowing many (not too small) objects to be held.

Building

Improvements could definitely be made regarding the building process. To start, we could have worked in a more organized manner. At the time of building, three team members were present. Since we were working on such a small project, and with the COVID-19 restrictions in mind, there were moments where one of the members was waiting until another member finished his part. Moreover, the fact that we worked quite ad hoc meant an increase in total building time. This also resulted in quite some broken parts, think of the connection points between the exoskeleton and the inner glove.

The gravest mistake we made came as a result of exhaustion. We started working at 11 A.M. and finished our first day at 4:30 P.M. This meant that tiredness began to set in. Since we were all right-handed, and hence had an inert bias to thinking from right-hand perspective. As a result, we mounted the exoskeleton on the left hand is if it were a right hand, Id Est the exoskeleton for the ring finger was placed on top of the index finger etc. Trivially, this had to be reverted, which put a lot of unnecessary stress on already somewhat fragile components.

By working according to a tight schedule, these problems could have been avoided. The fact that we managed to resolve the problems arising during the building process does speak to the inventiveness of the group.

CAD Design

With all things considered some changes in the Cad design could be made. As said in the Building part stress was applied on fragile parts, which broke off. In a new version of the Cad design these parts could be made a bit bigger. The design gets a bit bulkier but also has much more improved strength and grip. Another thing that could change is the slack between the joints could be increased so the parts can move smoother along each other. This gives the glove a higher wear comfort. The same holds for the holes made in the design. Due to printing the holes became a bit smaller than expected. Also, the rotational degree of freedom in the joints should be increased by designing the joints in another way. Now the hand cannot close completely. With all these improvements considered the clutching glove would be a lot more comfortable to wear and work even better.

11. Special topics

As a group we decided that each member should explore one special topic, resulting in a total of six.

The explored special topics are:

- Human factors design
- CAD design
- Cardboard modelling
- Physical modelling
- Haptic perception
- Haptic technology

Human factors design

The studied materials include: "**Handbook of Human Factors and Ergonomics, Fourth Edition**", chapter 51: Designing for people with functional limitations and chapter 52: Design for aging, and the online article "**Framework of Product Experience**".

After reading, a summary was made with all information relevant to our design/project.

Human factor design has evolved over the last years to become an independent discipline focusing on workings of human-artifact interactions, these interactions being viewed from a multidisciplinary perspective. This includes various fields of science, engineering, design, technology, and the management of human-compatible systems, which includes various products, processes and environments either from a natural or artificial origin.

Understanding how human-artifact interactions (in our case human-product interactions) work and by what these interactions are influenced, is of great importance, may be even essential, when designing a (new) product.

One needs to know if the final product can be used by the intended consumer demographic and more importantly, if they **want** to use it.

People, in general, have a spectrum of reduced abilities and impairments, in other words, a person may have more than one reduced ability or impairment.

For example, if a product is supposed to help a person with a certain impairment, and it's working is based on an auditory signal, this signal should be in the audible range that most people, even better all people, can hear. If the signal is not audible to people, they will not use the product because it does not work for them.

Our product is meant for people that have lost strength in their hand. However, we need to take the reduced abilities of the elderly into account because they could be part of the possible consumers.

The book discusses how in Chapter 52, how different reduced abilities should be taken into account whilst designing. The reduced ability that we should consider is the reduced reaction time of elderly and their slower movement and a number elderly have lightly shaking hands due to Parkinson's disease.

This means for our device that the pressure sensors should not activate the servos at the slightest pressure.

The slow movement has no particular on our design since our design focusses on the closing and opening of the hand itself, but it could be taken into account when defining the opening and closing speed, so that it is close to the normal speed.

To make the usage of our product as enjoyable as possible, we need to make sure that the glove is comfortable for the users. The comfortability depends on the material, how does the user experience the texture of the inner glove. The comfortability also depends on how noticeable the components are to the users, i.e. does the user feel the presence of the electronics or does the user only feel the inner glove, and the pressure of the mechanism when closing.

Summarized, the things learned from this special topic are the complexity and the working of huma-product interaction, and what (and whom) do you need to consider whilst designing a product.

Cardboard modeling

The special topic cardboard design consists of the educational module on the website[6]. After a short explanation of the tools, materials, and the basics, there are several videos about techniques and mechanisms following some examples.

Figure 16: Fold in the cardboard

For the preliminary design of the glove, we used cardboard, which was before used for boxes, in contrast to the softer (foam-like), 1-layer cardboard used in the explanatory videos. although the cardboard is slightly different, most of the techniques could still be applied. For example, angle cutting, in the way shown I the video, was not possible with the layered cardboard used, but there weren't any instances where this has caused any problems, since there were no fixed angels in the design except for a slight angle between the hand plate and the thumb plate (shown in figure 1). Here we cut the upper layer of the cardboard and folded the lower layer.

Figure 17: Connections

The remaining parts of the design done with cardboard are the rods connecting the servo motors to the fingers, using multiple parts. In the final product these are the moving parts, and these very are essential, so these should also be able to move in this preliminary design in order to make a good evaluation. For the rods we used strips which are connected using split pins as shown in figure 2.

Figure 18: Finger mounts

Finally, we added the servo motors and the finger mounts. The servo motors where made from foam using a basic shape with the right dimensions of the actual motor (figure 1). For the finger mounts normal paper was cut into strokes and rolled to create a short tube for the finger to rest in (figure 3).

Haptic perception

Haptic perception is a very broad subject with many use cases. It is mostly used to describe how things look like or what textures they have using your hands. Understanding haptic perception can be useful to make virtual reality more immersive, but also for making devices that make use of contact at distance like telesurgery, where a surgeon remotely controls a robot arm that performs surgery.

The feeling of textures is not very important for this project as it is low on our MoSCoW ordering list. However, with more time and budget to develop the device this could become really important. Your hands are very important to feel textures, shapes, temperatures and hardness or softness of an object. Because the device includes two gloves the feeling of textures becomes very difficult in addition to that temperatures are also very hard to feel as the inner glove is isolating and heat resisting. Feeling the shape and hardness of an object is possible through the gloves of the device, however it is more difficult because of the restricted movability of the hand. When enhancing this device in the future one could improve on those restrictions by implementing vibrations when the glove glides over a rough surface or by adding a form of force feedback to let the user better feel the compliance of an object. A heat sensor can also be added to give the user input on the temperature of the object.

The following topics are could be more important to our project.

Size-weight illusion

The size-weight illusion is an illusion that occurs when you pick up two objects of the same weight but of a different size, you automatically want to apply more force to lift the heavier object and less to the smaller object. This force is not just applied in the vertical direction but also in the horizontal direction as you want to get a better grip on the object. When lifting the two objects people think the smaller object is heavier. In the design process it has to be kept in mind to let the glove give the correct output force and not too little or too much, risking damaging the object by crushing it or by letting the object slip out of the glove because too little force was applied. Then there should be decided how much input the wearer of the glove gets about the force the glove puts out. Because the user gets no input in how much force the glove applies it should not be a problem that the user misjudges the weight of the object. A threshold pressure has to make sure that the glove does not apply to much pressure. This maximum pressure will be tested and adjusted in the testing phase.

Weight adaption

When holding an object of certain weight in the palm of your hand for a longer time you get adapted to its weight and you start to not feel the object anymore. This could be interested as the same effect might be seen when you hold an object of a certain weight for a longer time. The person wearing the glove might let the hand accidentally open when he gets used to the weight of the object and risk letting the object fall. In the testing phase we can see if this can happen on our design. Now we let the glove open by lowering the pressure of the sensors, but if this is not sufficient you could let the glove open by putting in a little more pressure before the glove opens.

This special topic showed how people use their hands to sense what an object looks and feels like. In addition to that also what kind of illusions a person experiences when feeling or holding an object. This helped when making and testing the device, that way the device would be adjusted to this and not make the same wrong 'decision'. In the making of this section the sources from the haptic perception special topic were used.

Physical modelling

While under detailing the final design is discussed, this section explains the iterative process of the physical modelling. This process revealed different possible problems that the theoretical model had and introduced some boundary values for parameters; these parameters have already been explained in the detailing section.

The first problem, which had to be solved, was the stimulation around the first joint of the upper four fingers. The upper four fingers (index, middle, ring and pinky) were chosen because of its similar movement. It also was essential to have an understanding of how the natural movement of one joint could be emulated most accurately; subsequently a similar mechanism would be used to stimulate the other joints of the fingers.

The first design depicts two rods with a non-rotary connection (indicated in the figure with a triangle). With one end connected to the servo and the other to the first finger segment. This allows the force to be applied directly to the top of the finger.

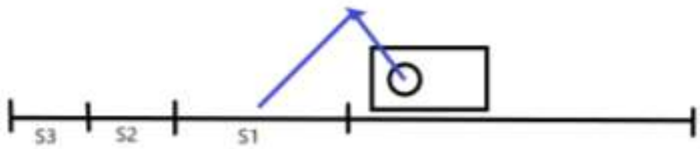

Figure 19: First design

This preliminary model imposed two problems: the connection point between the finger and the rods, would move over the finger segment, making the exoskeleton less comfortable and efficient, and the model did not allow for any force transfer to subsequent segments, which inhibits the possibility of moving other joints at the next finger segments.

In the meetings it was agreed upon that the exoskeleton must wrap around the object, which meant that this preliminary model was of the table. It was discovered that the rods must in some way have a pivot point at its connection point, allowing a force to be transferred to other segments.

This transference of force would be exploited in the second design in which all individual segments would be connected using a pivot point and a horizontal bar. When a force would be applied in the direction parallel to the hand palm a change in the angle between the finger segments and the individual rods connecting them, would cause every segment to be subject to a force vertically downwards, inducing a closing (or opening if reversed) of the finger.

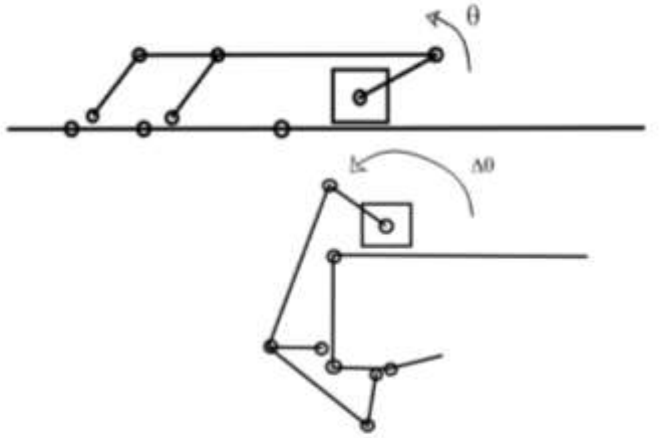

Figure 20: Second design

The major flaw of this model was the freedom of the exoskeleton to move upwards instead of applying a force downwards. Also, the third finger segment was not involved in the exoskeleton, which was important for measuring the pressure at the tips.

A possible solution was to make the design only able to apply a force downwards. While this proved difficult to implement into the design, the method of dissecting this problem was reversed by starting at the fingertips and working upwards to the servo. This led to the final design described in the detailing section in which the rods connecting the second and third finger segments are connected in a pyramid structure and in which the first rod connecting the servo has a starting angle with the palm of the hand of 90°; this only allows the exoskeleton to move downwards when shifting to a closed state.

For the thumb a similar technique would be used to close the thumb, although the thumb would be stimulated by one servo. Initially a design was chosen that did not involve a pivot point between the intermediate segments of the servo and the thumb. The parameters are explained in the detailing section.

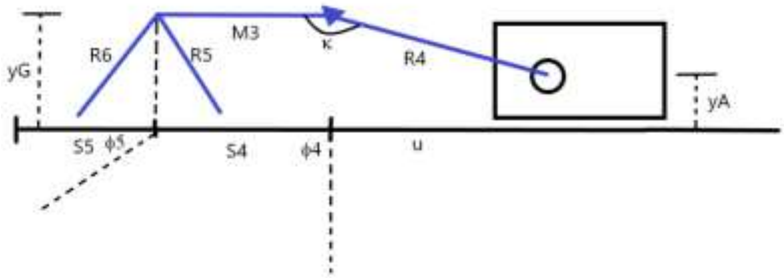

Figure 21: Final design

This design revealed a major problem in the flexibility, while segments M_3 and R_4 were unable to retract or extend, which caused the design to be immobile and useless. Subsequently a third segment was used to solve this problem of immobility.

Haptic Technology

Haptic technology, also known as kinaesthetic communication (= connected with the ability to know where the parts of your body area and how they are moving), is a broad field of applications. These applications include but are not limited to force feedback, vibrotactile feedback and smart materials used for haptic interactions. To understand haptic technology, it is of great use to understand the word 'haptic'. Haptic stems from the Greek word 'haptikos', meaning the sense of touch. According to Oxford Languages, haptic means "relating to the sense of touch, in particular relating to the perception and manipulation of objects using the senses of touch and proprioception". Hence haptic technology are those technical advances that can create an experience of touch.

I will describe each of these three subjects and discuss if they were of use for our project. Afterwards I will describe what I have learned.

Force Feedback:

The subject of force feedback contains a plethora of sub-subjects. Among these is the subject of Exoskeletons and lifting aids. I do not need to explain that this applies to our glove, which is in essence a lifting aid. Force feedback in the context of a glove is often described under the umbrella term of haptic gloves. Haptic gloves come in many shapes and forms but are in essence a kind of glove which allows the user to communicate with a computer. The way we will deploy this technology is via the servos connected to the fingers of the users. The way we exert these forces is via an exo-skeleton.

An exoskeleton is an articulated structure which the user wears over his / her hand, and which transmits forces to the fingers. In our case via servos. In the context of haptic technology, the exoskeleton and the exerted forces are mainly used for creating the sensation of touch, not applying extra lifting / clutching strength.

Vibrotactile feedback

Vibrotactile is an adjective described as 'relating to the perception of vibration trough touch'. This kind of haptic technology encompasses the majority of the field. They mainly use a type of ERM (Eccentric Rotating Mass) actuator. An ERM is in essence an unbalanced weight connected to a motor which turns around at considerable speed. Because of this, it generates vibrations felt throughout the device (much like the way a vibration motor works in your smartphone). This type of technology is mainly used for small corrections in movements, such as improving the balance of cyclists. Hence it is not of great use for our project.

Smart materials

Once more, smart materials are a broad field. It focusses mostly on the evolutionary systems developed by living organisms as a survival mechanism. Think for example of a chameleon who changes it topographical layout to reflect light in a different way, as to blend into its environment. Smart materials use these principles to design materials that can act responsively and generate different textures inside the glove. This material is static however, and not responsive. Hence this subject is not applicable.

In the end, this special topic was not of significant use. It was studied near the beginning of the preliminary prototype phase, as to gain insights into which ways we can construct our glove. Whilst the force feedback chapter was relatively useful to get insights into the way exoskeletons and lifting aids are designed and deployed, the other two chapters left much to be desired. This is mostly due to the fact that haptic technology has, in a broad sense, more to do with the creation of the sensation of touch, which was not the goal of our project.

Reading, and watching, through this special topic was not in vain however, since I did learn quite a few things about haptic technology. Although I did not deploy this knowledge directly into the project, it is useful knowledge to possess.

CAD Design

In this special topic was looked at the software siemens nx 12 to make a 3d model of the complete design. This was necessary in order to make the 3d printed parts. There were a lot of challenges in making the design. Which will be discussed in this topic.

The first challenge was drawing a hand since it should become a glove which is fitted on a hand. In order to model the design and get insight of the idea a hand should be modeled with the design. It was unknown how to model a hand beforehand, after watching a video on YouTube the option 'human hands' was found, which models the hand of humans.

After modeling a hand, the design could be modeled. First the holders on the hand where modeled by using round shapes which was easy to do so. After applying them on the modeled hand they would not fit properly. So in this case elliptic shapes where used. This was the next challenge since working with elliptic shapes was a new experience. The shapes should be defined in a larger and smaller radius. After a lot of time the perfect parameters where found and the holders on the hand could be modeled in the design which can be seen in a figure below.

Now the holders on the hands are in the model of the final design, however some attachments should be added. In this case when pressure is applied in the ends of the attachments the hand is closed. In order to make the attachments the physical model is used for the length needed. It is design in a way that M3 bolts and nuts can be used, this choice is made since M3 is a common size in the hardware shop and M2 is already less common. Also, M3 is not that bulky and the parts can remain small. The holes in the attachments are 3.3 mm this is done because the 3D printer has deviations and the joints should be easy to rotate since they are joints. The last step of the attachment bars was using edge blend so the parts would not feel sharp when touched. This improves the ease of use.

The final printing part would be the holder for the servos. This is not a sophisticated part and was easy to model. After taking the measures of the servos themselves, the part was easily modeled. Again, edge blend is used on top of the model to remove sharp edges.

The final challenge was the use of the constrains in the assembly of the model. The assembly is where all the individual parts come together. When the parts are put together they need to be constrained in order to get the correct degree of freedom. The first part in the assembly is the hand. The hand obviously got a fixed constrained. Since the had was modeled it could not move like a hand, so it could not open or close the hand. In holder to get the holders on the hand correctly they also needed a fixed constraint. This means that we could not model the movement of the hand to test it. The attachments where added after the holders on the hand. These could get the correct constrains since the holes should be aligned therefore the option infer center/axis could be used. So the holes are now aligned but the parts can still move on that alignment. Therefor 3d distance constrain is used. This means that the inner and outer part have a 3d distance of 0.2 mm. This is designed so the parts could easily move along each other in a joint. Now the attachments where aligned.

The final parts of the printed parts are added which are the servo holders. Before we can place them on the hand, we should have a place to attach the servo holders onto. So a plate is designed in order to attach the servo holders. This plate will be re-designed in real life since this will be an aluminum plate. The reason to design it in real life is that the hand on which the design should fit has not the same size as the hand in the model. So this plate is added for reference reasons only. The servo holders can now be added on this plate to make the design look more like the real-life design. For this reason also an Arduino and a 9-Volt battery is added. In the final design they will also be placed on an aluminum plate.

The connection to the servos is also not drawn but this will be done by using the screws that where attached with the servos. Now a few pictures of the final design will be shown to get more insight in the design and make this chapter a lot more understandable.

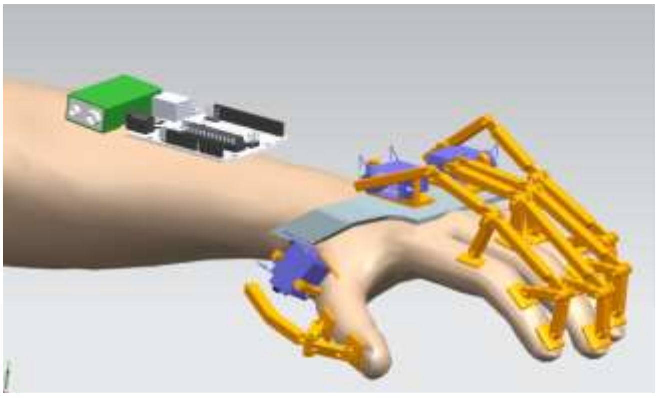

Figure 23: CAD-design 2

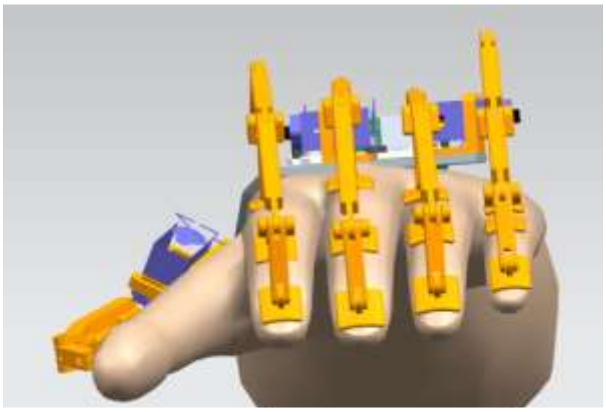

Figure 22: CAD-design 1

Some final remarks about the 3D modeling in the printing face. The servo holders did once destroy a print in the process since they came loose of the glass plate and then was inserted into other parts. So that print was corrupted while making a new print those parts where left out. In the prototype they are made out of aluminum.

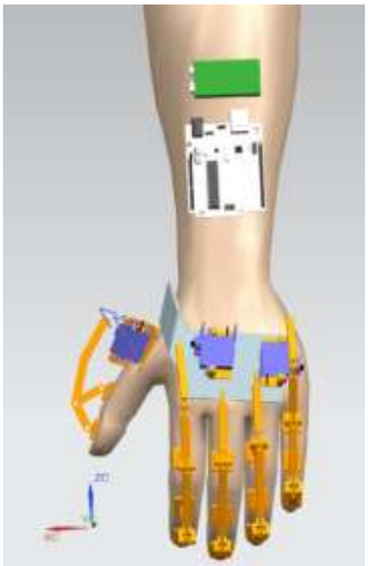

Figure 24: CAD-design 3

12. References

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13. Appendices

A. Values of the parameters of the exoskeleton calculated using Matlab.

	Index (*mm*)	Middle (*mm*)	Ring (*mm*)	Pinky (*mm*)
R_0	55	-	-	55
R_1	31.4907	28.1366	28.5424	31.9948
R_2	30	30	30	30
R_3	30	30	30	30
M_1	51.2252	56.2749	55.2914	48.877
M_2	64.7454	76.0683	74.2712	59.4974

Table 4: Length parts

Other relevant constants:

d	20 mm
β_0	30°
y_A	10 mm
y_D	70 mm
α *	56°

Table 5: Modeling constants

*α is the angle between M_1 and the line parallel to S_1 in the open state.

Values for the thumb.

R_5	26.907 mm
R_6	25.612 mm
M_3	36 mm
y_G	20 mm
u	32 mm
R_4	33.526 mm
κ	162.7°

Table 6: Thumb measurements