PROJECT:
EXOSKELETON HAND

Programme:

Global Business Engineering

Mechanical Engineering

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Preface

As last year Erasmus students at VIA we are unrolled for the final project. In this final project students have to use as many skills, learned during the education, as necessary to successfully finish the project. This is considered to be a final test in the preparation for the professional world.

The first step in this project is forming a group, this choice is related to personal interests. We initially formed a group of tree mechanical engineering students; Pablo Alvarez studying mechatronics in Spain, Jordi Comelles studying mechanical engineering in Spain and Felix Cornelus studying design and production technologies in Belgium. We had a few ideas but soon we agreed that we want to go on with the idea of an exoskeleton hand. Afterwards a fourth person joined the group, Candice Morant. She studies global business engineering.

Making this project would have been impossible without the help of other people. Therefore, we would like to thank these persons:

Per Ulrik Hansen, for his technical guidance throughout the semester.

Lene Overgaard Sørensen, for her help in the business part.

Morten Bornemann Kristensen for assistance with the 3D printing

Martin Møhl, who taught us a different way and methodology of working in a project.

Doctor Stephen Koun and the physiotherapist Christina Christensen, who helped us with the professional knowledge in medical areas.

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Executive summary

The purpose of the exoskeleton hand that we create, is to help people with a disability with their hand to use it again for grabbing, picking some objects.

We combined different aspects of construction of the product (mechanics and electronics) but also different variables in the market (marketing, communication, financial) to sell the product on the Danish market.

Based on different researches on exoskeletons done, not only in Denmark, but in the world we have developed an exoskeleton hand in order to help people with a lack of strength in their arm or hand. A product like this needs some information relative to the medical sector but also on patients and their different diseases that they have. Some interviews have been led to understand, know how to develop the product but also about the market and potential customers.

All along the project, the team had faced several problems due to a lack of knowledge in the human body, diseases relative to a lack of strength in the arm and hand. It was difficult to develop a good product with a good quality and reliability, taking into considerations all different aspects, possible disagreements that patients can have.

There are only some prototypes of exoskeleton hands which have been created. Those prototypes are well developed and required a lot of researches and knowledge in human body, mechanics and electronics.

Concerning the business analysis, we have to first describe the external environment to know where the product will develop. All conditions were important to permit a good development. An internal analysis about the customers, competitors, substitutes and distributors were essential. We had to know the principal environment related to the exoskeleton hand.

After looking forward the external and internal environment of the product, we had to decide which target group we wanted to focus on. The interviews, the country of development of the product, the economic situation of each inhabitant was important to take the decision. Moreover, the communication through different should be adapted to our retailers.

A financial part was necessary to calculate different costs about the exoskeleton hand, mechanical and electronical part. A budget had to be done to know approximately the

number of exoskeleton hands that we could sell and how much they will bring back to our company. We had to know if the product had a chance to be sold on the market.

1 Introduction

All around the world, there are minorities experiencing common mobility problems due to degenerative illnesses, accidents or even born ones. We will focus in particular on people having some hand strength and movements problems.

Exoskeleton hand technologies for rehabilitation and assistive engineering have not progressed as rapidly as the exoskeleton robots and devices for lower and upper limbs that have become popular over the last decade.

There are many possible disorders that may have this specific effect: carpal tunnel syndrome, when there's a high pressure in nerves located in the carpal tunnel. Chronic Inflammatory Demyelinating Polyneuropathy (CIDP), which cause progressive weakness and decline of the sensory capabilities in limbs/extremities.

Tendinitis, where a tendon (or more) suffers inflammation. Also myopathies, muscular diseases that can be caused by genetic inheritance or acquired during lifetime. Another possible disease is multiple sclerosis, related to the nervous system, where the individual experience a constant a progressive decline in the body, therefore losing movement and strength capabilities.

This last one is widespread all around the world, with a larger incidence in first world countries, such as Western Europe, where approximately half a million inhabitants are affected. Even if this disease affects the whole body, many affected people would appreciate having control of their hand for a longer time. Helping them to fulfil daily tasks in an easier way motivates the design of our product, the exoskeleton hand, which will resolve partially those problems and improve their life conditions.

There have been delimitations regarding this project, being the following ones: in business area, the target has been the Danish market, along with an overall analysis of the price, focusing deeper on the chosen strategy and budget. About technical aspects, electronic components are commercial models, and the designed part is focused only in the exoskeleton functionality, being commercial and external the battery chargers, not being included in this project their technical drawing nor documentation. Relating to mechanical knowledge, self-designed components shall be limited. There are delimitations in the medical section too, due to the extent of the project, no further researches have been done in anatomy or ergonomic aspects.

How to create an affordable and comfortable device that helps people suffering from loss of strength in their hand so they can fulfil daily tasks?

We will see in a first part a presentation of the product, then the different methods used all along the project, ideas concerning the power, controls, actuators and the structure of the exoskeleton hand. A part on the design of the product containing a part on the electronics, electro mechanisms and the different results that we had. We will analyse a business section with marketing, actions taken, different communication ways used for the promotion of product and a financial part will be seen for selling the exoskeleton hand.

2 Criteria's

At the end of the project, the result will be compared to the problem formulation made up in the beginning of the project. In order to compare these, the problem formulation needs to be divided in sub problems that are measurable. In the table below values that characterize the sub problems are shown. These are result of collecting information out of the survey and discussion within the group.

Criteria's	
Specification	**value**
Autonomy	12hours
Weight on the arm	500gr
Total weight	1kg
Load per finger	200gr
Closing time	3s
Design	Human
Control	Intuitive
Materials	Eco friendly
Wearable	-
Discrete	-

Table 1. Criteria's

Not all of these criteria's can be easily measured. Some of these specifications can only be tested or compared to similar products.

3 Presentation of the product

The exoskeleton hand is a robotic hand in the aim to help people with a lack of strength in their arm or hand due to an accident, a degenerative or a born disease. The system will work with a battery to charge. A pop-up will appear on the hand when the battery will start do be down to alert the patient that it must be charged.

The product can be placed on the market of medical devices. In fact, the exoskeleton hand will help people with a disability to use their hand, to help them to grab, pick some products like a glass or a pen for example. Our product is not like a prosthesis but it is a help. The system will be over a glove to put.

Concerning the physical aspect of the hand, the user will just have to put a glove on their hand. The mechanism will be visible by others. The electronic part of the product will be wear in another part that the hand, to secure the user. The product will help them in daily life, to be more independent.

The exoskeleton hand will be done on measure to fit to the size of the hand on the patient. Moreover, the glove will exist in different colours to correspond to different genders, ages and personality of customers.

Moreover, the user will have two possibilities to have it. The first one will be to order it by doctors, then fix it to the necessary size. The second option is to order the product in a complete kit.

Concerning the use of the hand, some maintenances will be necessary to keep the exoskeleton hand functional. Apart from obligatory maintenances, there will have a warranty of 1 year for the body part and actuators and 2 years concerning the electronic system.

4 Methods

4.1 Mind map

One of the first steps of this project was the making of a mind map. This mind map was helpful for creating an overview and structure. The mind map that shows the structure of the exoskeleton hand can be found in the appendix.

4.2 Survey

4.2.1 Goal of the survey

The interviews were organized and fulfilled with a realistic approach, being their objective to gather practical data, needed for a user oriented design.

4.2.2 Outcome

The interviews were a useful asset in the project, providing professional medical point of view to the project. The opinion of the doctors and physiotherapists involved influenced in the designing, changing the exoskeleton to a more flexible and adaptive model. Their main contributions were:

- Physiotherapist Christina Christensen pointed out the most common problems for patients, their general opinions and symptoms, along with the most used hand positions (grabbing, picking up small objects, hand rotation around the wrist).
- Doctor Stephen Koun's knowledge about anatomy and medicine caused a redesigned in the product, as a consequence of his remarkings about comfortability, anatomy (muscle evolving in such conditions) and user iterations.

4.3 Weighted score table

In this project there where many decisions to make. To make sure that these decisions are made from a non-personal point of view, we used a weighted score table to compare options.

4.4 VDI2221

A project such as this needs structure in order to succeed. The VDI2221 "verein deutscher ingenieure richtlinie" fits perfect for this project. It divides a big overall problem/challenge into smaller parts. These smaller problem are easier to solve. In this project the overall challenge designing an exoskeleton hand is divided in sub problems.

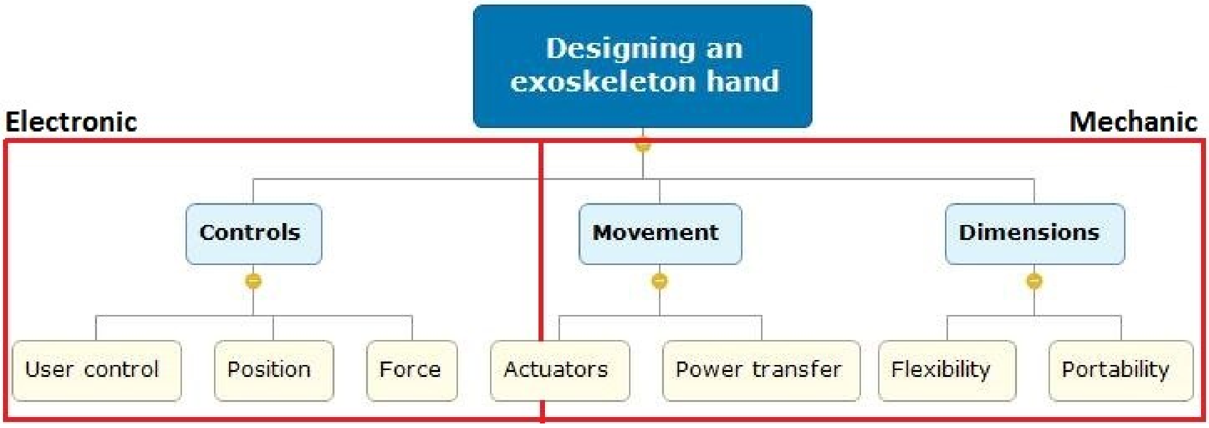

Figure 1. Exoskeleton hand diagram design

This diagram shows how the sub problems where divided. They can be grouped into two different groups, electronics and mechanics. These groups work together but can be worked out separately.

During the project these sub problems where handled apart from each other. Of course some of them are related to each other and need an overall solution. The goals for each of these problems can be obtained by processing the requirements of the hand.

After finding solution for these sub problems, the sub solutions where put together to create the hand. This putting together brought some problems with it because some solutions counteracted. This mend that some sub solutions had to be adjusted to fit in the overall design.

To conclude, the VDI2221 method was very useful in this project, it created structure. But at the other hand its dangerous to handle the sub problems so separately that it is impossible to find an overall conclusion. Because of the good communication in our team we could avoid this problem.

4.5 Prototype

As engineers was mandatory for us to create a prototype as a test field of our calculations and design, for being able to check the results as a previous way to achieve our goals of making the exoskeleton hand real. In fact, the prototype experimented many design changes, due to calculations and decisions.

In our project there were two clearly differentiate parts for prototyping: electronics and mechanical design.

4.5.1 Prototype development

Before achieving the final result many designs have been created and discarded due to the constant improvement. An important detail in the prototype is that is has been done for one finger, instead of the whole hand (as it would be in the final product), as a consequence of constant improvements, which cause that once one model is tested, new mistakes are discovered, so with that feedback its redesigned again. If we had done experiments with the whole hand, this process would have been slower, because 3d printing time for one finger was already high, but for all of them, it was excessive.

First of all, the 3D part has been modified several times, because when designing it has been discussed the result and viability of each model when they were created. Therefore, the designing didn't stuck in one definitive model, but new issues and ameliorations showed up in the process, such as the implementation of a LCD display or of the sensors.

Also, a comparison between different types of systems for the finger movements (electric, pneumatic, electromechanical...) had already been done, so the type of exoskeleton structure was already decided, resulting in starting earlier the design of the frame and structure in relation to the chosen system. Most of the models were printed in PLA, making use of the 3d printers provided by the university.

As seen below, there are some previous and final designs, being able to compare how the exoskeleton evolved during the project.

Figure 2. Prototype development (fingers)

Figure 3. Prototype development (palm)

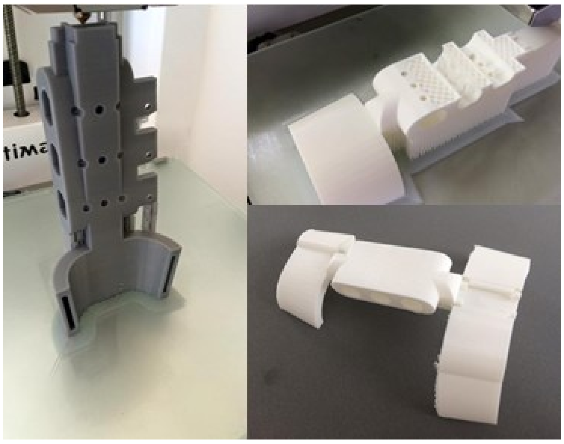

Figure 4. Prototype development (forearm)

The prototype, regarding mechanical aspects, consisted on a glove, made with an elastic material, having attached PLA frames and pieces, using glue. Those pieces are located in both sides of the glove, so cables can be attached and the finger may move. In the upper part the opening system, which includes the spring can be found, also attached with glue. In the forearm the other main piece can be found, with the actuators and the display, along with gaps in the frames where the wires are located. This last structure, is fixed to the forearm using Velcro so it’s easier to adapt to the user’s body.

While the 3d designing was being created, electronic and control systems were also being calculated, simulated and tested.

Each part was measured to check if the output given was the expected according to the simulations, like the voltage or the current in a specific section of the circuit, or the sensors electrical resistance in relation to a force or position (depends on the type of sensor), so it was possible to calibrate it with the controller and the written code a posteriori used on the final prototype.

First important aspect was motor control. First control test done over the motors using bipolar transistors, specifically the model PN2222, as a basic motor control method. Operation was simple: One arduino digital pin, PWM type, is connected to the base, and the motor is located in series with the transistor, with two possible layouts: in one the motor is placed between the emitter pin and ground, and in the other between supply and the collector pin of the transistor. The second type gets a higher current in the motor. If using this method a diode should be placed in parallel with the motor, so the peak of voltage when stopping doesn't overload the transistor. This method was used on a DC motor located in the lab, due to the waiting for the proper components, being useful to obtain knowledge about the range of voltage and current operation.

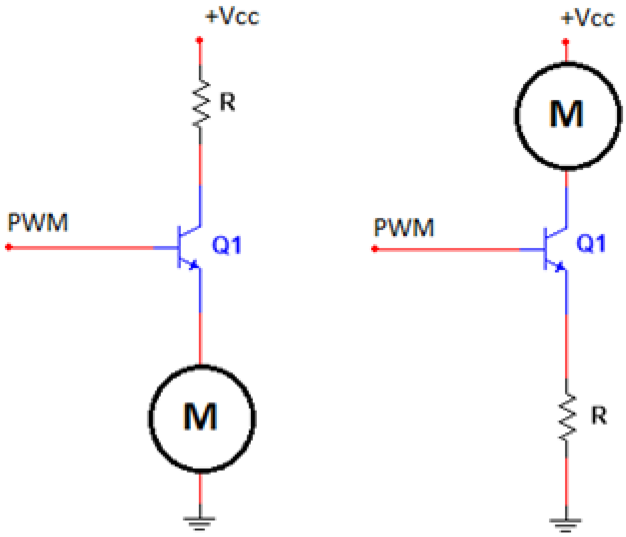

Figure 5. Motor transistor layout.

Afterwards, when designing the prototype, were two requirements were stablished: being able to invert polarity, so it could spin in both directions (opening and closing the hand), and speed control. First motor controller to be used was TLE5205, which allows to control one motor in both directions.

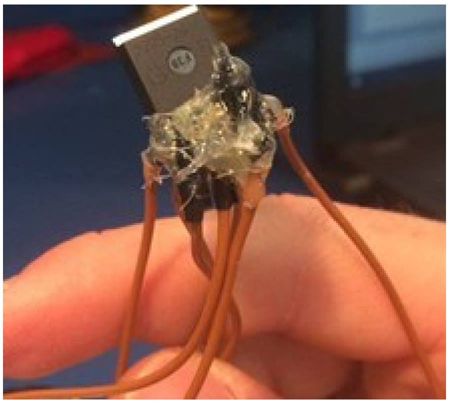

Figure 6.TLE5205 - Wire soldered version.

However technical problems aroused, like error reports from the chip (pin 2, EF), or controlling its speed, because there was no direct PWM option. One way of getting that would be to use PWM on the supply pin, but our supply was planned to be 12 V (5 V is quite low for supplying the motors, having in mind that that's the digital control voltage), so due to the complications this chip was discarded. Another option was chosen, L293D dual DC motor controller. With this one, it was possible to control both directions and speed of each motor. Additionally, each chip could control two motors. In the end this last model was the chosen one, accomplishing an appropriate command response, behaviour and simple control.

Previous to be ordered, it was tested in the free online application powered by Autodesk, named 123d.circuits. The circuit was the following one.

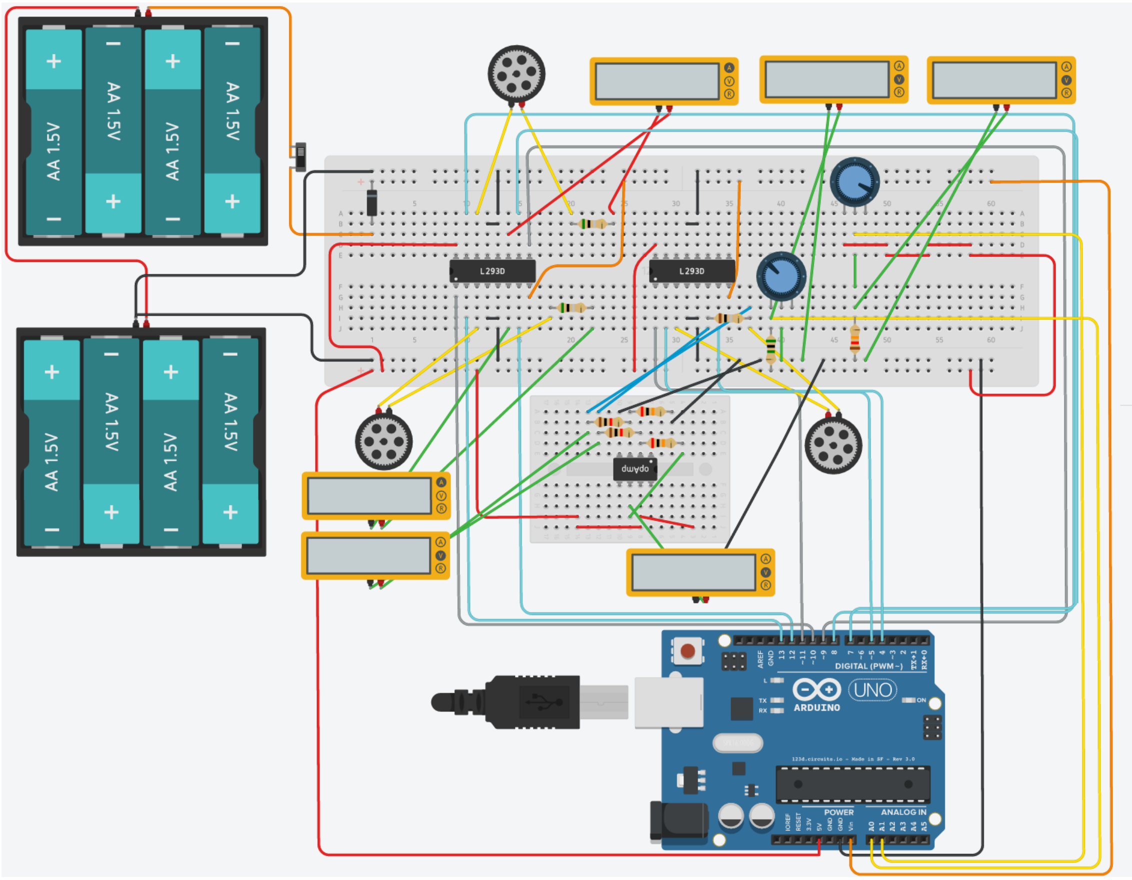

Figure 7.Simulation circuit.

Being the schematic the next one:

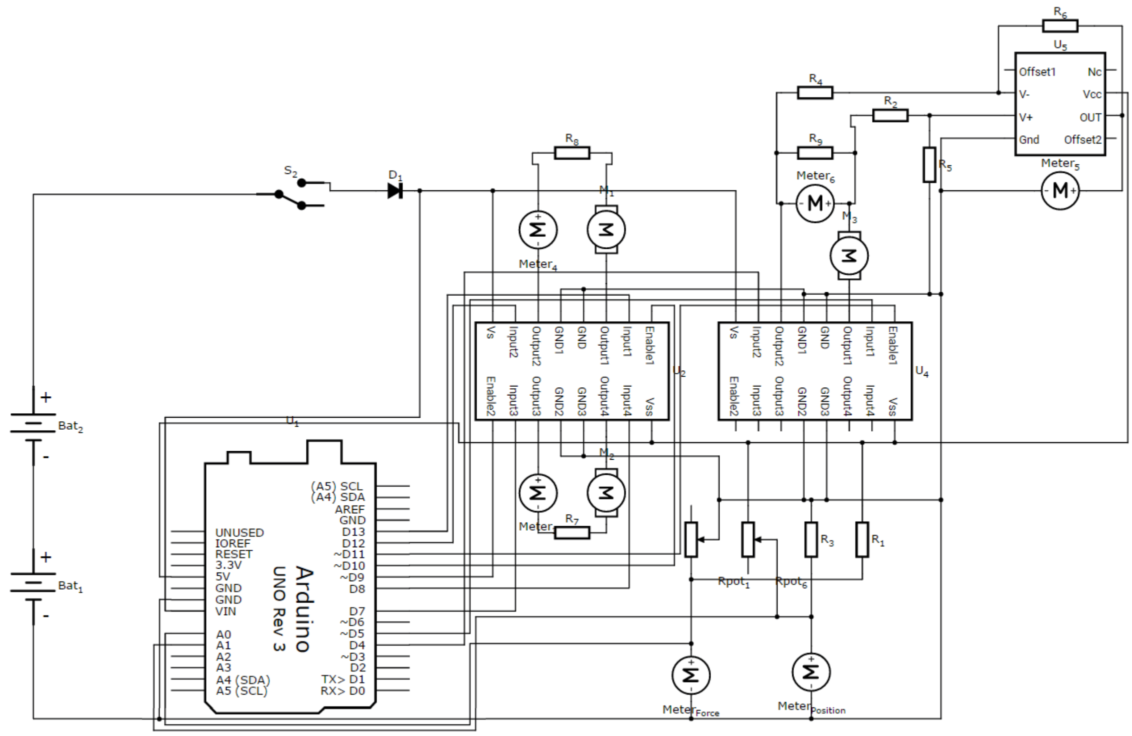

Figure 8. Electric simulation schematic.

According to the code located in the code appendix, this circuit is able to spin three motors, depending on the data obtained from two potentiometer, which are considered the force and position sensor. Current measuring was tried, but measurement were unsatisfactory.

Position and force sensors didn't suppose several issues regarding measurement. The first one behaved perfectly, with constant values in fixed positions. On the other side, the force sensor, due to its high resistance value, was more unprecise. There were additional complications, specifically integrating the sensor in the frames. With the position one the size was adequate, however with the other one, we could have worked with longer or shorter lengths, but this one supposed several issues in the designing, not being integrated in the frames due to lack of time.

In relation to sensing the motor's current, there were difficulties too. First it was going to be sensed using the chip ACS712, which presents in theory a simple behaviour and, depending on the model, many possible sensitivities. However, the obtained data with our model was unprecise, which was suspected to be partially caused, as it was discovered later, by a connection problem, along with a low accuracy for low currents. This connection problem has its origin in the type of component: SMD (surface mount device). This type of devices presents a compacted format, with short pins, so they can be soldered in a pcb, being ideal in electronics. In our case, due to the lack of a pcb, several wires had to be soldered to its pins, resulting in an breaking of the wires (inside the isolation plastic) and the pins, being unable to keep testing the component.

Afterwards that method was replaced by another based on measuring the drop of voltage in a resistor. It could be done in different ways, but due to the broad range of possible currents, the limited range of measuring Voltage of the amplifier and Arduino together, as the main problems, it couldn't be done in time for the prototype.

About the interface, it was implemented a functional one, which could display several parameters, depending on the loaded code. However, it had an unexpected behaviour in some situations, showing on the screen unrecognisable characters for a normal user.

Electronic and control components, and its supply, aren't fixed in this prototype to the user, being mostly (but for position sensor) in a board, or next to it. Instead of a battery, a DC supply has been used, and no protection components such as fuses, diodes or switches have been placed.

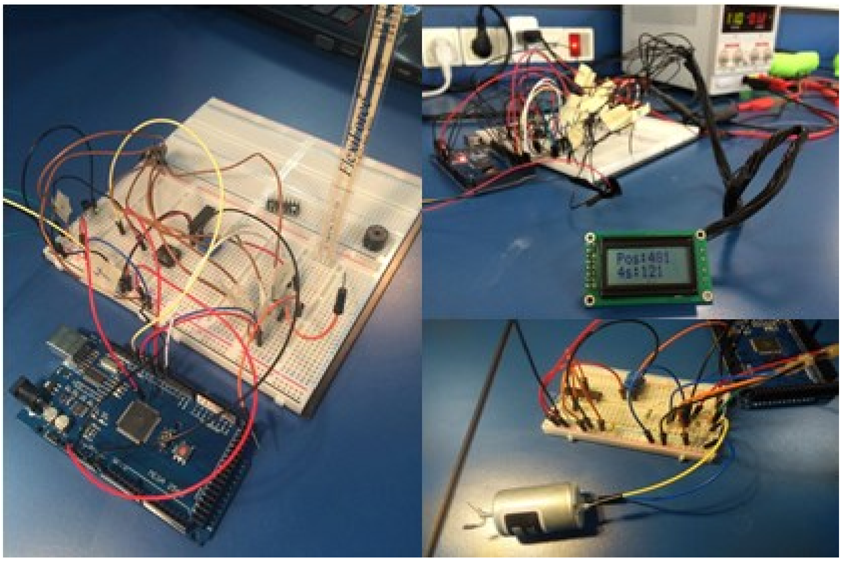

Figure 9. Testing

More pictures of the prototype can be found in the appendix.

4.5.2 Benefits from prototype

This process of prototyping has generated a number of conclusions, related to its different issues, being helpful in order to achieve an appropriate design:

- According to the World Wide Web data, there are relations already established for fingers related to hand dimension and arms, but according to that there are seven different shapes of hands, so it was difficult to pick one and design for it.
- The dimensions that have been chosen for the previous models were different to each human, so we needed to decide who of us was going to be the guinea pig for the prototype, so we could have feedback from the design and, consequently, improve it.
- The comfort was also an important goal to achieve, because the final design must be as much wearable and comfortable possible for the user.
- When designing we figured out that is not easy to take measures of hands and arms, and then directly design, because the human body parts we were measuring are not rigid due to muscles and fatness. Consequently, the exoskeleton needed to be re-designed to match perfectly.
- Force transmission through the cables. The prototype used fishing cables, which exceed our requirements, but there were problems involved. One was the route it takes, between the fingertip and the actuator, because it's under the hand, so at first, it was decided that it should go around the hand till the upper part. However, it could be harmful for the user, and there will be losses, so the design changed, having, in most of the route, the transmission cable inside a plastic one, so losses would be reduced and an increased safety could be assured.
- Plugs and wire associations. Several electrical wires are headed to the arm, specifically to force and position sensors in the hand, the three motors and the display, which supposes 26 in total. One solution was to associate them in three groups: one to the hand, other to motors and the third one to the screen, but in their way to the arm they could be attached to each other, so the discomfort is minimum. Also the type of connections, between components, PCB and Arduino. The PCB would be connected to Arduino as one module, having pins soldered to it, measured to coincide with Arduino pins.
- Where to place batteries and control system, so it's less annoying and heavy for the user. It was decided that the client would carry a belt pouch, with two slots: one for the batteries, and another for the control system (PCB and Arduino).
- Motors' location, which is critical for the product. There were three options: place them in the hand, forearm or upper arm. The closer they were placed to the fingers, the higher the force could be, and lesser volume it would require. However, that supposes

also an increased discomfort for clients, so in the end they were placed in a middle position, the forearm.

- During the electronic part, it was complicated to decide which sensors were appropriate according to the requirements and parameters to measure.
- Measuring the grasping force, which derived into trying to measure current, which caused several issues in the designing.
- Integrating position and force sensors into the frame.
- The first idea for initiating finger's movements were pushbuttons, but they required a relatively high force when activated. Added to that problem, the finger frame is fixed to the user's body so all the parts were moving at the same time, and those pushbuttons had a poor accuracy. Therefore, the flexi force sensor was tested and it proved to be the solution for that problem, due to a lesser force for being activated and being more precise. The output is an analogic signal instead of the digital one of the pushbutton, so there are more possibilities when calibrating.

5 Generation and evaluation of ideas

5.1 Power

One of the first decisions was related to supply energy. This decision had plenty of influence on the further outcome of the project. Different types of power require different types of actuators. And different types of actuators fit on different types of hand structure. Therefore, it was very important to compare the different types of power.

5.1.1 Pneumatic

A pneumatic system exists basically out of a compressor unit, valves and pneumatic actuators.

The compressor is in this application of the volumetric type such as the piston compressor. This compressor is driven by an dc electromotor. The compressor unit could be equipped with a tank. But because of the small sizes and limited airflow the tank is not necessary.

Figure 10. Pneumatic compressor

The valves of the pneumatic system have a big influence on the controllability of the hand. In this case electromagnetic 3/2 valves would be a good option. These valves control single way pistons. These are returned by a spring.

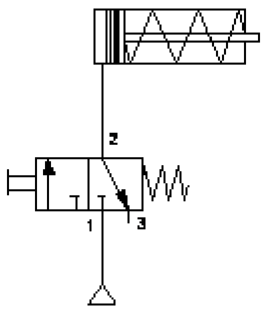

Figure 11. Pneumatic piston sketch

These valves could be proportional valves to make the action more controlled, but because of the size this is difficult. It is a better option to control the speed and force of the motion by controlling the electromotor. Because there is no tank in the system a motor control can control the piston movements.

To conclude, this system would have a high speed, but would be unprecise for middle positions. Furthermore, it requires a pump unit and a battery, which would be more uncomfortable to the user in terms of weight and noise.

5.1.2 Hydraulic

Similar working principals as pneumatics, pump creates flow and this flow results in pressure and so force in the actuators. The big difference is that with the hydraulics there must be a return line for the oil. It is slower than pneumatics the good thing is that it works with higher precision and can easier be controlled. At the other hand there are some disadvantage. Because the used fluid, in this case oil, cannot be released, there has to be a tank. This Means extra weight and complexity. Another disadvantage is that the oil can irritate the skin in case of leaking.

5.1.3 Electromechanical

The electromechanical model uses a battery wish powers and electromechanical actuator such as a motor. The main advantage is the controllability; electronic circuits can easily control these motors. Furthermore, it is characterised by a lower weight and reduced volume and power consumption, along with and increased actuator typologies offer. A disadvantage of the electromechanical system is that almost all the actuators start from rotational movement.

5.2 Controls

5.2.1 Display

Communications systems could be approached from different angles. One option was a total control using an interface composed by buttons, switches and potentiometers, so in the case the exoskeleton were in the right hand, it could only be controlled using the other one. Another option was to provide intelligence using sensors. This last one supposes an autonomous arm, accomplishing the goal of being able to control one arm with no external help. In this last model an LCD display would be added, showing battery levels and sensor monitoring. The chosen model is the last one, so no other type will be considered in the next sections.

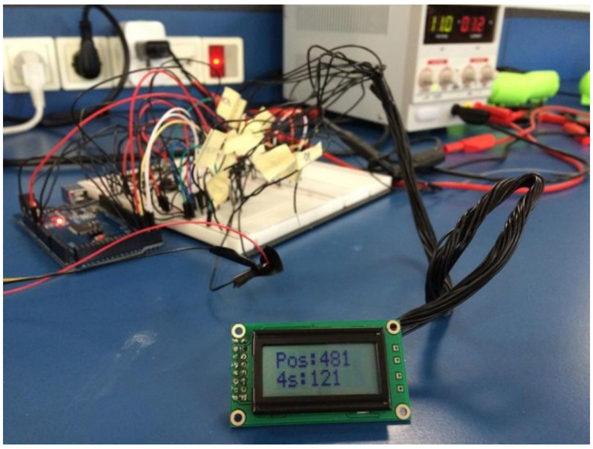

Figure 12. Display force and position testing.

5.2.2 Position detection

Position is an essential parameter when controlling actuators, avoiding to open or close in excess the fingers, which could end harming the user or his/her environment.

Therefore, position techniques were searched for. One way was acquiring motors with integrated limit or position sensors, like the models sold by Firgelli (explained further in 3.2). The first type would suppose many disadvantages, because there would be no way of knowing the exact position, unlike the one with position sensors, which would accomplish our requirements.

Another option was to acquire a linear potentiometer, which would be fixed to the movement wires and driven by them. A third one was thought, implying also potentiometers, but rotational ones, located in the finger joints, so the angle could be measured.

Last option was a resistor dependant on bending, named flex potentiometer. Aligned with fingers, they could be used to determine their situation.

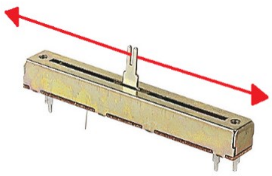

Figure 13. Linear potentiometer

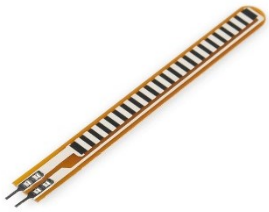

Figure 14. Flex potentiometer

5.2.3 User commands

There are different ways of receiving user's intentions. One would be with surface EMG sensors (Electromyography), which are able to detect electrical activity, so when the client would try to grab an object, that command would be sensed and interpreted by the measurement system. They would be located around the arm, in strategic points.

The other type would be using force sensitive resistors (FSR), which change their resistor value according to the force they receive, such as, in relation to user commands, detect the pressure from the fingers and activate the motors.

At last it is also possible to use standard push buttons to communicate with the control board. They exist in very small sizes, this makes it possible to put between the frame of the exoskeleton hand and the fingers. Furthermore, they are cheap and reliable. The problem with these buttons is that they don't measure the applied force. They also require a certain force to be activated. This force is not adjustable, which means that it is hard to synchronize them with the rest of the system.

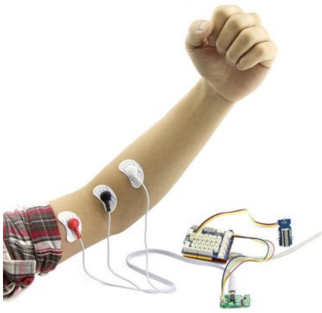

Figure 15. EMG sensor

Figure 16. Flexi force sensor

5.2.4 Force detection

Detecting directly whether the hand is holding an external object supposes a complication, as it depends on the contact area. That would be the main problem using FSR sensors: location and quantity, not forgetting fixing them to the glove, and the fact that the hand would be quite overloaded with sensors.

A different approach would be current measuring: placing after the motor (in row layout) a small resistor whose value is known, so through reading the voltage drop on the resistor the current could be obtained, and the force could be calculated, due to the direct relation between current and delivered force. For more information see part gear-motor and electric circuit.

5.2.5 Safety

Additionally to functional specifications, the exoskeleton must fulfil protection measures. To create a safe device, there should be at least two different emergency stop options. A mechanical safety and an electrical safety. On the electronic systems a switch is added in the power supply, so the supply can be cut out. There are also safety components in electronic circuits.

- Mechanical (magnetic) safety

An automatically mechanical safety is needed apart from the electrical because the user cannot control the totality of the safety system. Also we need to take into account that the electrical safety can fail so we need a trustable safety that on any scenario must work perfectly.

The best option is to attach two magnets on the pulling cables to avoid high tension forces on the fingers and high grabbing forces so when the limit is reached the safety will actuate.

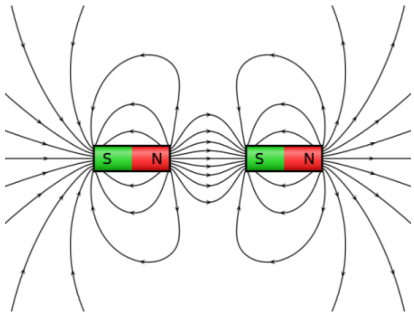

Figure 17. Magnetic field between two bar magnets

The system consist in two small magnets that their attracting forces are located on the safety limit, so when this limit is overpassed the magnets will disconnect one with the other so the cable will not pull any more.

The magnets are located in a bigger tube that is a part of the normal tube. The magnets still have space to move inside of the tube. When the dangerous situation is over the magnets will easily come back together. This means that the system repairs itself.

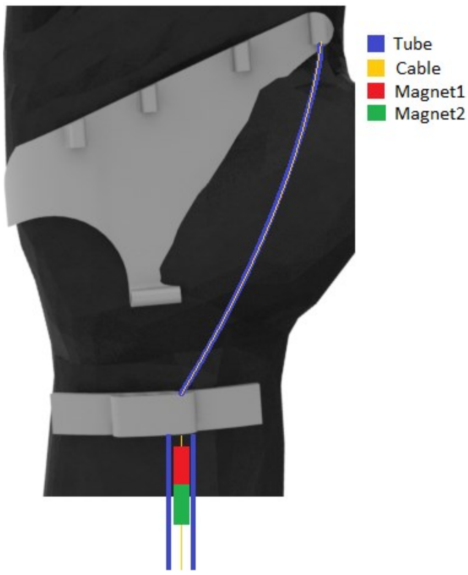

Figure 18. Magnetic safety

5.3 Actuators

On this part, we tried to figure out which was the best actuator for the movements of the fingers comparing the different systems and evaluating them according to our requirements and standards of qualifications.

The table for comparing the different actuators is shown further.

5.3.1 Pneumatic/hydraulic pistons

The pneumatic and hydraulic systems were previous ideas using the air and oil as fluids to drive each devices (pistons for pulling the cables for the movements), but the common problem of each were the subsystem required; pumps, pistons, cables and the total weight was a problem for the user, because our aparatus is focused in people with less strength on their arms. Controlling the position with accuracy was difficult with both systems, also the speed was a shortcoming so they have to many disadvantages in relation to the other systems, for that reasons they were discarded.

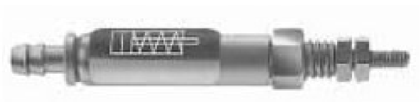

Figure 19. Pneumatic & hydraulic piston

5.3.2 Electric linear actuator

The different linear motors were the best options (see the table below) for doing the movements (pulling the cable) for the fingers because they are very accurate with the position and they have feedback, so we require lighter springs for pulling back the fingers to the standard position, it must be said that in terms of force and speed weight and consumption (very important for dimensioning the batteries) they had good marks but for prototyping we decide to use winder motors due to the cost of an actuator.

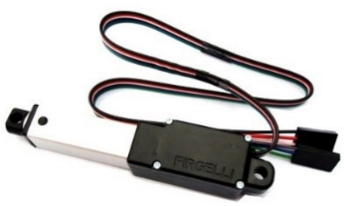

Figure 20. Electric linear actuator

5.3.3 Electro winder motor

The winder and gear motor were our cheapest options for the prototype, they have also good rates according to our standards with some shortcomings like force or speed, but for proving that our prototype is reliable were the best choice, so we decided to go further with them and test it with the Arduino controller.

Figure 21. Electro winder motor

The table below shows the comparison of the different actuator options.

Type	Price	euro	Weight	Mass(g)	Speed	mm/s	Control	Stepper/dc	Force	N	Compactness	Dim(mm)	Consumption	W	Total
Factor [1:5]	1		4		1		4		2		4		5		
1-Pneumatic	4	50	3	pump 500, pist 100 (300 total), valve 100g (300 total): total weight 1.1Kg	3	High	2	Complicated	5	100N @ 5bar	5	pist 140x20, pump110x90x50	1	42W 3.5A (pump) +170 mA (valve)	62
2-Firgelli PQ12	3	57 +Control	9	15 (total 65)	7	6 (max 10)	8	Normal dc (have feedback)	8	40N Peak	8	21.5x15x67.5mm	9	3.33-2.52W (550mA 6V - 210 mA 12 V)	171
3-Firgelli L12	3	62 +Control	8	34-40 (total 140 g)	4	2.5 (max 5)	8	Normal dc (have feedback)	8	45N Peak	7	18x15x(90-110)	9	3.33-2.64W (550mA 6V - 220 mA 12 V)	160
4-Firgelli L16	3	62 +Control	7	56 (total 180 g)	5	4 (max 8)	8	Normal dc (have feedback)	4	175N Peak	7	20x18x122	5	7.8W (650mA12 V)	129
5-Hydraulic	5	40 (actuator+pump)	2	1.8 Kg (everything, 3 actuators included)	3	High-	3	Complicated	7	50 N 3.4 bar	5	pist 140x20, pump 90x40x35	4	10W 12 V 700mA (pump)+170mA(valve)	82
6-N20 reductor motor	8	10 +Control	9	20g/per act (80 gr)	5	4,8	6	Normal dc	6	20N	8	80x12x12	9	3W max	162
7-Winder motor	9	5 +Control	8	30g/act (110 gr)	6	18,8	6	Normal dc	3	600N	9	58x12x12	8	5W max	153

Table 2. Comparison of different actuators

5.4 Structure

The structure of the exoskeleton hand is a combination of components that create the base of the device. They are controlled by the actuators that are mounted on them. Depending on the type of actuator there are some different types of structures.

The selection of structures consists partly out of structures based on existing exoskeleton hands. But most of them are ideas created in our group. The structures compered further one in this topic are the structures that we considered as being useful. Because of a lack of time we were not able to test all of them. This means that scores and conclusions are based on simulations and reasoning's.

It's important also to mention that in some cases the possible actuator options influence the scores of the certain structure. This is unavoidable because not all the actuators can work on all the structures.

The comparative score table below was used to determine the best option. The different systems a described in the part type of structure.

In the table we use factors such as complexity, reliability, durability … These factors cannot be related to numbers our measurable specifications, this made it hard to compare them. Nevertheless, they are important factors, so many arguments were used to defend or prove personal findings.

The normal open cable/spring system turned out to be the best option.

Type	Price	Wei ght	Finge r mobil ity	Tecnhi cal comple xity	Use r Safe ty	Safe ty	Cont rol	For ce	Compact ness	Durab ility	Mainten ance	Desi gn	Comforta bility	Realiz able	Move ment speed	Total
Factor [1:5]	2	5	4	3	4	2	4	3	4	3	1	3	2	5	2	
1-Multibody system (MS)	4	2	7	4	6	8	5	8	4	8	5	4	6	5	8	224
2-Flexible actuator system (FAS)	3	7	6	6	6	4	5	5	6	6	8	6	6	7	5	255
3-NO Spring cable system (NOSCS)	6	6	6	7	6	7	5	6	7	5	8	8	7	8	7	280
4-NC Spring cable system (NCSCS)	6	6	6	8	4	2	5	4	5	5	8	8	7	8	7	265
5-Lever system (LS)	5	2	4	2	6	9	5	4	2	9	7	3	6	4	8	185
6-Torque system (TS))	2	1	3	1	6	3	5	4	6	4	6	1	1	1	10	140

Table 3. Structure comparisson table

5.5 Type of structure

5.5.1 Multi body system

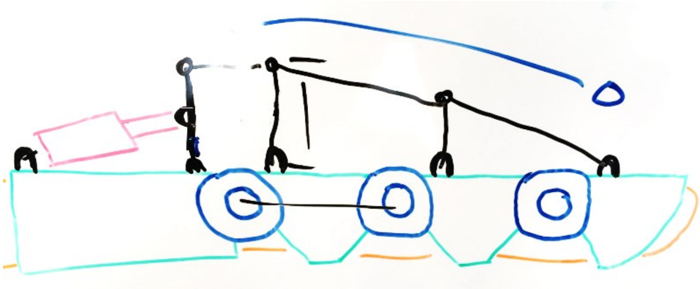

Figure 22. Multi body system

In this system all the finger parts are connected by joints. The actuator is situated on top of the hand. The actuator controls a system of frames that simulate the natural movement of a finger.

Being more précised the actuator must be linear pulling or pushing the frame for the closing or opening operation. This natural movement is a result of using the right dimensions for the frames.

Advantages	Disadvantages
Rigid system	Many joints
Natural movement	Complex frame
Direct control	Big

Table 4. Advantages and disadvantages of the multi-body system

5.5.2 Flexible actuator system

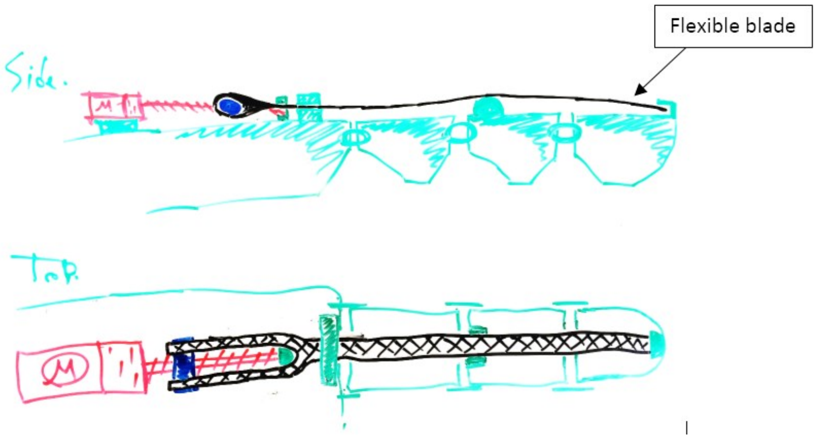

Figure 23. Flexible actuator system

This system is using a blade made of a flexible material (Kevlar for example) . The actuator (In that case a motor rotating a screw) pushes the blade away by turning. Pushing the blade, it will start bending and pressing the finger down. Because the actuator is pushing on the top of the finger, it's very important that the finger parts are connected by joints. This will prevent pushing all the finger parts away from users hand.

Advantages	Disadvantages
Simple	Joints
Flexible	Fragile
Compact	Low grabbing force

Table 5. Advantages and disadvantages of the flexible actuator system

5.5.3 NO cable/spring system

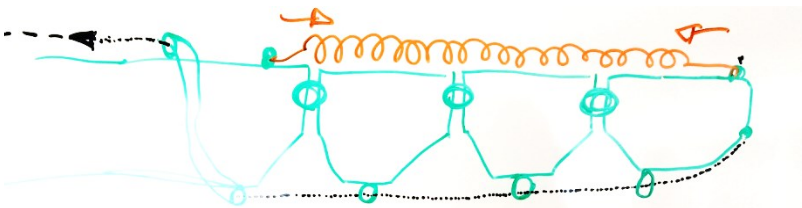

Figure 24. No cable/spring system

This system uses a cable to move the finger during the closing operation. The cable is fixed on the end of the finger and is guided true the finger parts to the hand. When the actuator pulls the cable, the finger starts closing. To open the hand, the actuator just releases the cable and the spring on top of the finger stretches the finger again. Because the cable is pulled by the actuator, joints between the finger parts are not necessary.

Advantages	Disadvantages
Simple	Cable running under hand
Flexible	-
Compact	-
Actuators not in hand	-
No joints necessary	-

Table 6. Advantages and disadvantages of the NO cable/spring system

5.5.4 NC spring/cable system

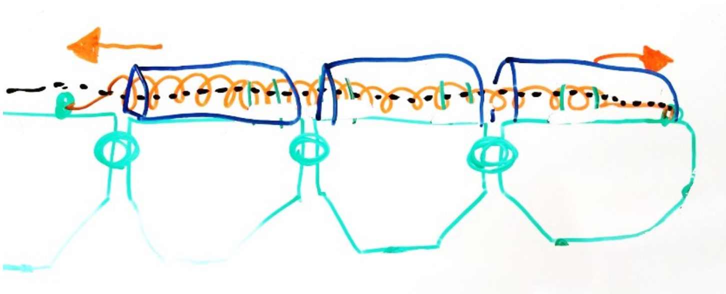

Figure 25. NC spring/cable system

This is a similar system as the no spring/cable system. The difference is that in this system the cable is pulling the finger open while the spring is closing the finger. Also the cable and the spring are located on the upper part of the finger, going through the spring covered for avoiding being stuck with the surrounding objects.

Advantages	Disadvantages
Simple	Force limited by spring
Flexible	Joint necessary
Compact	-
Actuator not in hand	-

Table 7. Advantages and disadvantages of the NC spring/cable system

5.5.5 Lever system

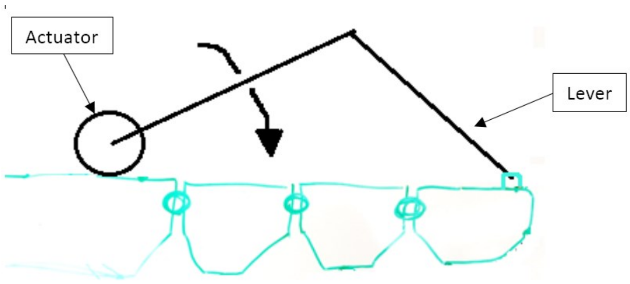

Figure 26. Lever system

In this system a rotational actuator such as a servo rotates a lever. This lever is connected to the top of the finger. When the actuator rotates the lever the finger closes. There is also the option of having a lever for each finger part.

Advantages	Disadvantages
Direct	Big
Easy construction	High torque required
-	Heavy

Table 8. Advantages and disadvantages of the lever system

5.5.6 Torque system

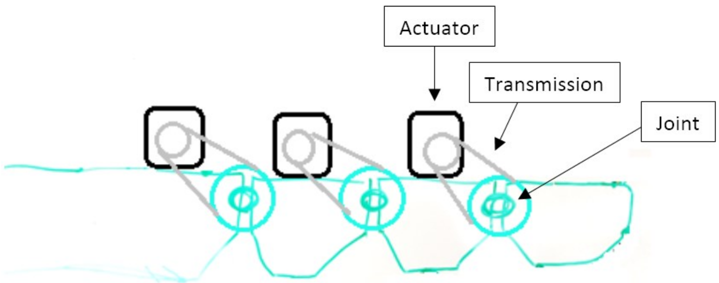

Figure 27. Torque system

In this system a rotational actuator such as a servo rotates the joints of the finger parts.

Advantages	Disadvantages
Direct	Complex
Easily controllable	High torque required
Precise	Heavy

Table 9. Advantages and disadvantages of a torque system

5.6 Materials

First of all, we are going to focus on the materials required for the frame defining and comparing each to find the best according to our standards.

This part of the project is based on the study of the different materials that can be used for the frame of the exoskeleton hand and the major components of the structure (forearm, fingers …).

- The first priority is the weight so our final costumers cannot wear a heavy device, must be comfortable and wearable as light as possible due to their force is reduced because of the muscular problems.
- The second priority is the availability of the components, for that reason we focused our path on materials that can be printed in a 3D printer so the design of each device depending on the measurements of each person (every person in that world have different dimensions of fingers and hands) could be easily created in less than a week and the patient can continue with his life.
- The third priority is the use of materials that not harm our planet (avoiding the electronic components, wires, actuators…) so we looked into bio plastics like PLA and biodegradable like PVA for building the structure , but always having in mind the other 3D printable plastic such as ABS , or polyamides like nylon or fibre reinforced nylon.

List of plastics:

- PLA
- ABS
- POLYAMIDES
  - Nylon
  - Fibre-reinforced Nylon

Figure 28. Plastics filaments

<u>Legend</u>

FDM: Fused deposition modelling, is a fabrication process used for modelling prototypes and production in a lower scale.

Fused deposition modelling uses an additive technique, depositing the material in fine layers to form the piece. A filament of plastic or metal that initially is stored in rolls is introduced to a nozzle. The nozzle is located above the material melting temperature and can be displaced in three axis electronically controlled. The nozzle normally drives motors or servomotors depending on the size of the printer and the piece is built with fine threads that are solidified immediately after coming out from the nozzle.

SLS: Selective laser sintering is an additive manufacturing (AM) technique that uses a laser to sinter powdered material (normally metal) aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure.

PLA (Poly-lactic acid)

PLA is a biodegradable polymer obtained from primary renewable sources such as sugar cane, corn-starch or even potato starch. One of its principal characteristics is its low shrinkage after 3D impression, so hot printing platforms are not needed on the impression using FDM at 185°C and are obtained pieces with more accuracy. Besides, thanks to its non-toxic nature this material can be used in many fields like medical, such as suturing and surgical implants, due to its decomposition is an inoffensive lactic acid.

Also is used on the fabrication of products in contact with foods, but must ensure that the extruder is made of stainless steel. With these characteristics PLA is the most environmentally friendly solution and one of our first options for the prototype and the final model.

PART	Quantity	WEIGHT	PRICE
Forearm	1	100g	35,428 €
Fingers (3parts)	5	50g	18,494 €
Spring holder	3	6g	-
Palm cable guider	1	7g	-
Elastic holder	3	3g	-
Cable guider	1	2g	7,707 €
	Total	168g	61,628 €

Table 10. PLA frame price

Prices obtained from www.3Dhubs.com

We must remark that the prices are obtained from an external source, so if we print them by ourselves is much cheaper due to the filament of PLA for example cost 28.95€ per kg and we need 166g of this material per exoskeleton hand.

On the previous table spring holder, palm cable guider, elastic holder and cable guider prices were obtained all together because the pieces were too small.

We must remark that the prices are obtained from an external source, so if we print them by ourselves is much cheaper

ABS (Acrylonitrile Butadiene Styrene)

Principally ABS is an amorphous thermoplastic based on petroleum very resistant to impacts.

This is the material contained on Lego piece's, also used on body automotive, home appliance and the cases of the smartphones. It belongs to the thermoplastics family or thermal plastics but it contain a base of elastomers based on polybutadiene that makes them flexible and resistant to impacts.

ABS is melted between 200 and 250 ℃ and can withstand very low (-20℃) and very hot temperatures (80℃). Besides its high resistance, this material allows obtaining a polished surface, is reusable and can be weld with chemical process (using acetone for example). However, is not biodegradable and it shrink with air contact, reason why the printing platform must be preheated avoiding the deployment of pieces.

ABS is mostly used on the FDM technic and in consequence is available in the major personal printers like Replicator 2, Markebot and the Ultimaker (the ones that we are using at VIA) making easy its manufacturing also like PLA.

Price table:

PART	Quantity	WEIGHT	PRICE
Forearm	1	100g	35,428 €
Fingers (3parts)	5	50g	18,494 €
Spring holder	3	6g	-
Palm cable guider	1	7g	-
Elastic holder	3	3g	-
Cable guider	1	2g	7,707 €
	Total	168g	61,628 €

Table 11. ABS frame price

Prices obtained from www.3Dhubs.com

As on the PLA price table, the spring holder, palm cable guider, elastic holder and cable guider prices were obtained all together because the pieces were too small. And is need to be said that the weight is the same of PLA because the pieces are too small and the density is really similar, so the variations of weight are insignificant.

Polyamides

Objects in polyamides generally are made of fine powder, grained and white using SLS technology, but some families of this material, like nylon, are presented with filament form and are used with FDM technic.

Thanks to its biocompatibility, like PLA, polyamides can be used to produce pieces in contact with foods (avoiding the ones which contains alcohol), and on the contrary of PLA and ABS, surfaces can be more smooth without ripple effect.

Being built of semi crystalline structures, this material presents a good equilibrium between its mechanical and chemical characteristics, where it comes it stability, rigidity, flexibility and resistance to impacts. Those advantages give a step to a huge spectrum of applications and a high level of detail. Its high quality is used, for example, for producing gears, pieces for aerospace market, automotive, robotics and medical prosthesis or for injection molds.

- **Nylon 6/6**

Nylon 6/6 is an artificial polymer belonging to polyamides family. Is produced formally by poly-condensation of an diacid with an diamine. The quantity of carbon atoms on the amine chains and the acid can be indicated behind the initials of polyamide PA (PA6-PA66…).

Nylon is one of the most complex materials for 3D printing. Its principal problem is the lack of adhesion to the printing plate, causing a lots of errors during the printing, and also a warping very difficult to control. Besides, usually gets humidity so , previously for the printing, is needed to dry it on the oven between 3 and 4 hours.

In exchange of all of those difficulties, nylon is a very resistant material, wih low viscosity, very resistant against temperature and with many varieties that give to nylon flexibility, transparency

It melting point is at 263 °C and the recommended extruding temperature for 3D printing is between 240 and 280 °C, with a maximum adhesion from 265 °C.

Price table:

PART	Quantity	WEIGHT	PRICE
Forearm	1	105g	100,20 €
Fingers (3parts)	5	52g	82,32 €
Spring holder	3	7g	17,55 €
Palm cable guider	1	8g	21,08 €
Elastic holder	3	3g	7,50 €
Cable guider	1	2g	9,85 €
	Total	178g	238.05 €

Table 12. Nylon frame price

Prices obtained from www.3Dhubs.com

In that case was possible to obtain the price of the small pieces separately because the material is more expensive

- **Fiberglass-reinforced nylon 6/6 (Gf30)**

The symbol Gf30 means the percentage of fiberglass on its composition, this polymer in comparison of the simple nylon has a lot of advantages offering higher strength to weight than aluminium and is up to 7 times more rigid and 5 times stronger than ABS. This material is recommended when needs parts that are durable and resistant to impact with a cost effective, and as strong as carbon fibre.

The disadvantages are:

- Not recommended for smaller, intricate parts.
- A minimum detail size of 0.8mm is required.
- Angles greater than 40 degrees usually needs supports
- The minimum wall thickness is 3mm

Price table for Fiberglas-reinforced nylon:

PART	Quantity	WEIGHT	PRICE
Forearm	1	106g	113,11 €
Fingers (3parts)	5	53g	94,17 €
Spring holder	3	7g	22,77 €
Palm cable guider	1	8g	23,57 €
Elastic holder	3	3g	9,92 €
Cable guider	1	3g	12,52 €
	Total	180g	276,06 €

Table 13. Fiberglass-reinforced nylon frame price

Prices obtained from www.3Dhubs.com

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MATERIAL	ABS	PLA	NYLON 6/6	F-R NYLON 6/6 (Gf30)
Produced from	Petroleum	Plant starch	Synthetic	Synthetic
Properties	High strength Durable Impact resistant Slightly flexible Heat resistant	Good strength Though Some impact resistant	Durable High strength Flexible	Very Durable. Highly Strong.
Extruder temp	210-250 °C	180-230 °C	220-260°C	230-270°C
Printing difficulty	Moderate	Easy	Moderate	Moderate
Price **filament 1.75mm**	29.90€/kg	29.90€/kg	39.90€/kg	43.90€/kg
Density $\left(\frac{kg}{m^3}\right)$	1050	1240	1230	1270
Tensile strength (MPa)	41-45	60	81.35	190
Positive points	Great plastic properties. Smooth finish. Solidifies quickly. Durable and difficult to break. Ideal for mechanical parts.	Bio plastic No heated print bed necessary. High print speed and resolution. Less warping or shrinking issues	Durability High elongation. Excellent abrasion resistance. Highly resilient. High resistance to: insects, fungi and animals molds, many chemicals.	Same as nylon 6/6 with high durability and strength Really good and smooth surface finish that don’t need post processing manufacturing.

Negative points	Petroleum-based. Non-biodegradable. Heated print bed necessary. Deterioration through sunlight.	Slow cooling down Low heat resistance Easier to break then ABS Needs thicker walls then ABS	Attacked by oxidizing agents, and strong acids High notch sensitivity Lack of being biodegradable and general pollution	Very similar to nylon 6/6 with better properties against acids. Lack of being biodegradable.

Table 14.Materials comparison.

6 Final design

6.1 Electronic

6.1.1 Circuit design

The system described in previous sections requires at least a supply unit, actuators, sensor system, a display and a controller. The following picture summarizes the electrical subsystems.

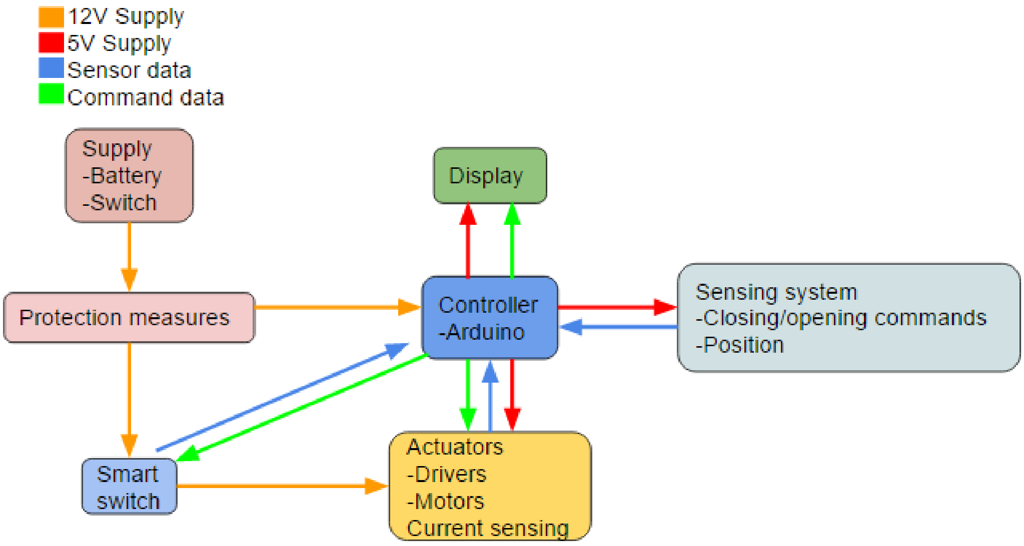

Figure 29. Overall electronic block diagram

As we can see, according to the schematic the following readings would be obtained by the microcontroller:

- Battery voltage level, after the protection measures and the smart switch
- Current measurement, from the actuator system
- Force and position, from the sensing system.

There are two different voltage levels: 12 V, used to supply Arduino and the motors (through the drivers), and 5V, obtained from the voltage converter inside Arduino. With those 5 V the display, smart switch, current sensor and also the motor drivers can be supplied. In relation with the battery, there's a commercial one included in this project, with a voltage of 11.1V. Even so, in the electrical and control sections we will talk about

12 V, and calculations will be mostly for 12 V, even when sometimes some of them use 11.1V too.

The complete electrical system is composed, according to the physical layout, by the control system, where most of the components are located, being composed by the PCB and the Arduino Mega. There are also two switches, the battery, and the arm system, which what we name to display, motors and sensors in the hand. All these components would be connected to the PCB, being this one together with Arduino, with socket pins soldered to the PCB and connected to the Arduino board. To assure a proper connection, and avoid disconnection, both of them would be attached to each other by bolts and nuts, 4 in total.

In the next drawing, designed in KiCad, the electrical components located in the PCB can be found.

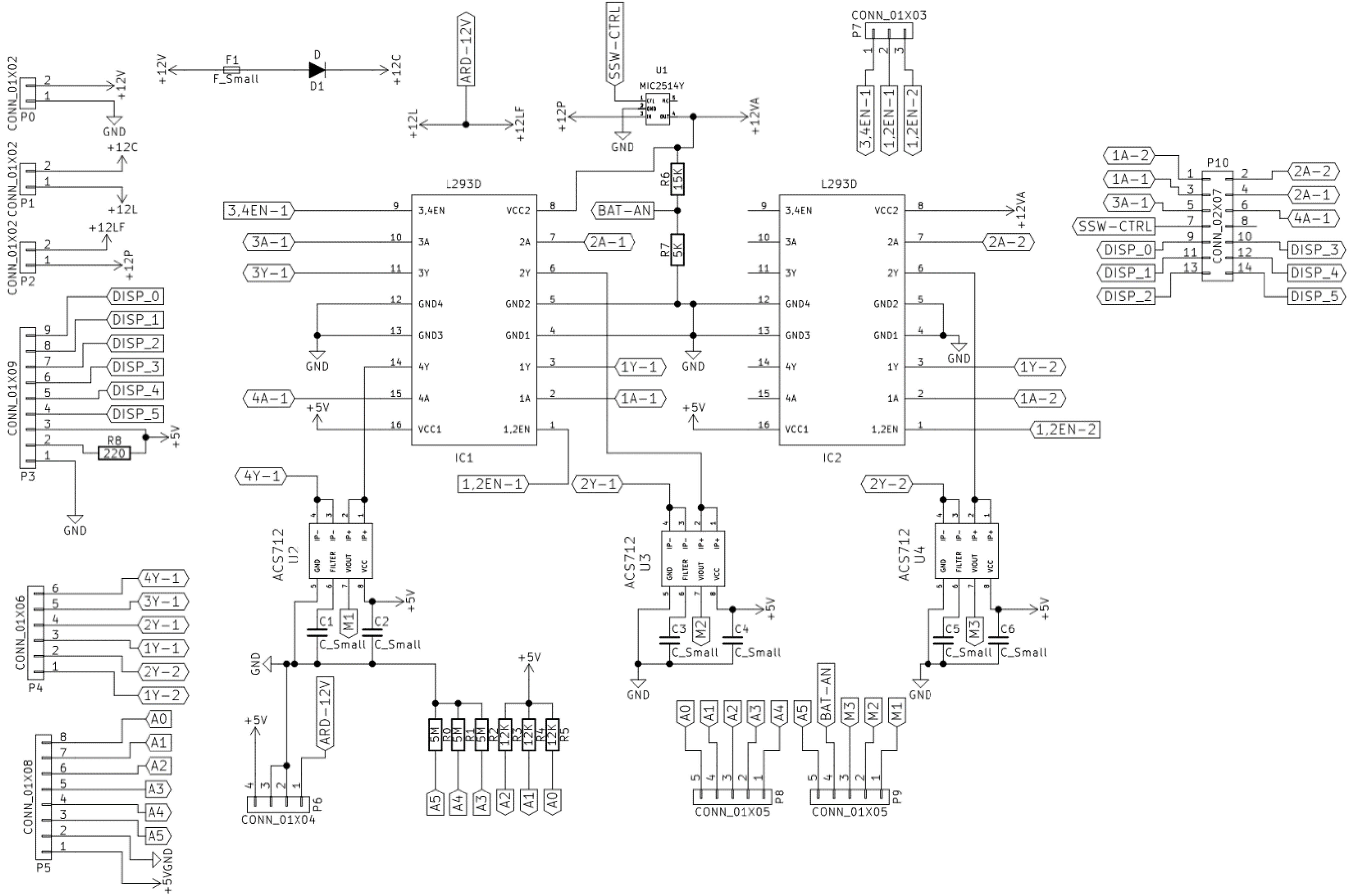

Figure 30. Schematic electronic circuit

As a reminder, motors, switches, batteries and position and force sensors are not drawn there.

From that schematic we obtain, using the same program, PCB circuit. Next picture shows it with all the layers overlapped. In the appendix they can be found classified in different documents:

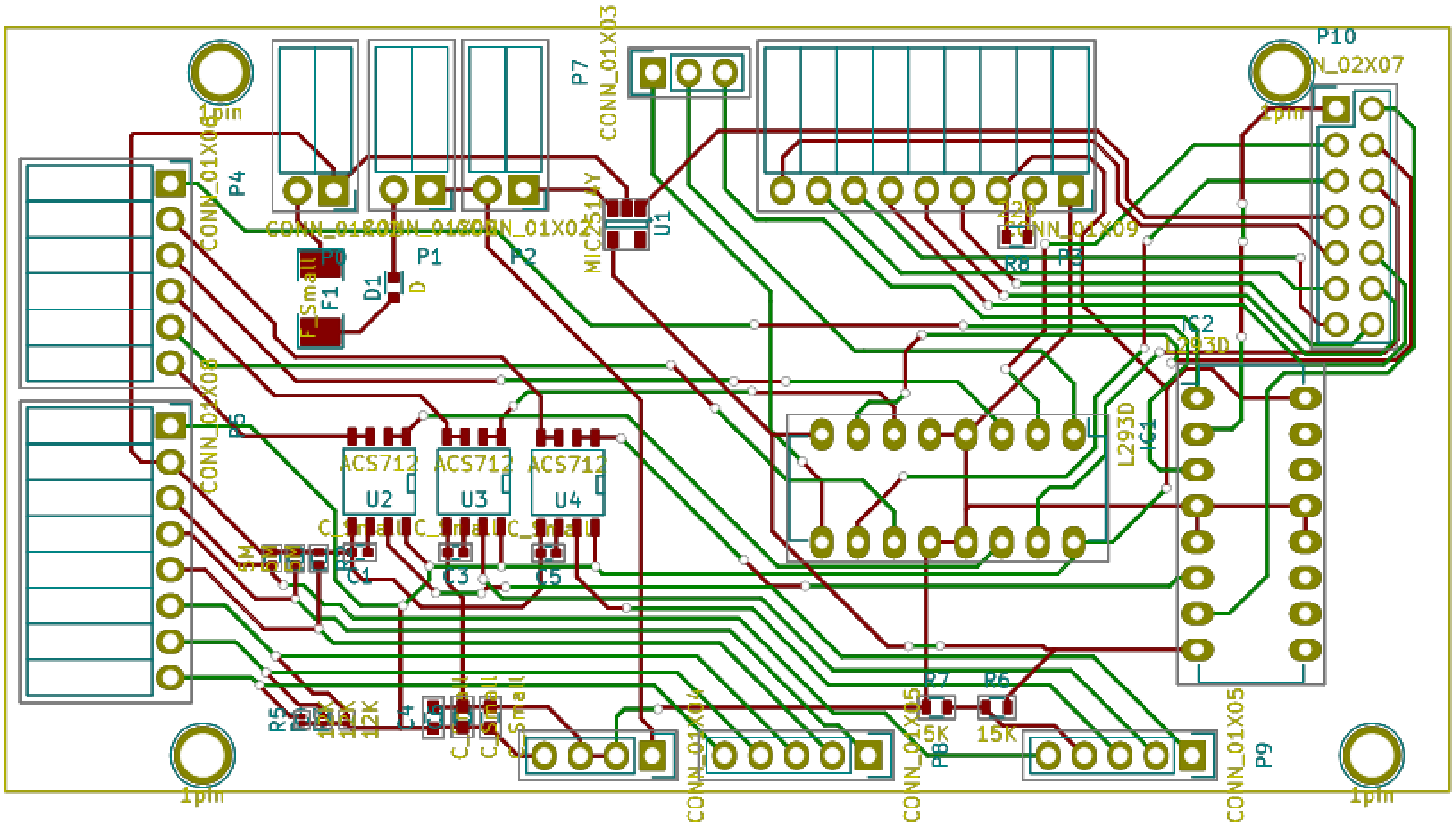

Figure 31. PCB electronic circuit

6.1.2 Circuit explanation

In this layout there can be found the power part, upper left, were the battery pins would be connected in P0. The positive voltage, named +12V, goes through a safety step, meaning the fuse, for overcurrent, and a diode to protect against reversed polarity in the battery, in case its pins are connected in the opposite pins.

Then it is connected to the power switch for the whole system, which is outside the PCB, so the wire go to connector P1. Then, after P1, 12V phase (+12L) supplies Arduino, and is redirected to the second electrical safety, related mainly to motors, so in case they cause trouble or even risks they can be shut down immediately. This electrical safety includes first another mechanical switch, followed by a smart switch, model named MIC2514Y. This smart switch is controlled by Arduino digital pin 28 (P10, pin 7). From this component, motor drivers and battery level sensor (resistors R6 and R7) can be supplied, and in case motors behave dangerously, or the battery level is higher (damaging therefore these chips or the battery measuring input of Arduino, A9 in our circuit).

Next section in the circuit is force and position sensing, located in the schematic in the lower part. Resistor 0-5 are the ones connected to such sensors, being R0, R1 and R2 connected force ones, and R3, R4 and R5 to position ones. These connections are located in the left down corner, in P5, along with a 5V and GND pin. P5 is the plug where the cable directed to the hand is connected. Those same cables are connected also to P8 and P9, which are connected to Arduino using straight male pins. P8 and P9 are connected to analogic pins of Arduino, for reading voltages.

Next section here contains motor control and sensor current reading, which are mixed together. Two drivers control the motors, being supplied with 12V for those actuators, and 5 V for the chips. Each chip is able to control 2 DC motors at the same time, in our case we have three, so one chip won't be completely used. These motor driver are connected to Arduino, for speed control (connected to P7) and polarity (P10, pins 1 to 6), and to the motors (and therefore current sensors). Motor pins go to connector P4 and current sensors U2, U3 and U4, specifically pin 4Y, 2Y in IC1 and 2Y in IC2 to such sensors and 3Y, 1Y in IC1 and 1Y in IC2 to P4 connectors. From those sensor the IP- pin of each is connected to P4 too, so here is where all the wires from the motors (6 in total) will be connected. These current sensors are connected to Arduino too, to report the current sensed.

There is also the display connections, which come mostly from P10, pins 9-14, and are connected to P3, along with 5V, GND and a small resistor used to power the backlight of the display. To P3 would be connected, therefore, the display.

In the following table a connection summary can be found:

Label	Connected to	Type of connection
P0	Battery	Wires
P1	Power switch	Wires
P2	High power switch	Wires
P3	Display	Wires
P4	Motors	Wires
P5	Hand sensors	Wires
P6	Arduino - Supply pins	Soldered male pins
P7	Arduino – Digital PWM pins	Soldered male pins
P8	Arduino – Analog pins	Soldered male pins
P9	Arduino - Analog pins	Soldered male pins
P10	Arduino - Digital pins	Soldered male pins

Table 15. Circuit connections

And in the next table Arduino pins that would be used:

Pin	Connected to	Function	Pin	Connected to	Function
5V	5V	5V supply to components	A9	R6-15K/ R7-5K/	Battery level reading
GND	GND	Ground	D22	IC2 - Pin 2	Control motors polarity
Vin	12L (12 V)	Supply to Arduino	D23	IC2 - Pin 7	
A0	R5-12K/P5 Pin 8	Position measurement	D24	IC1 - Pin 2	
A1	R4-12K/P5 Pin 7		D25	IC1 - Pin 7	

A2	R3-12K/P5 Pin 6		D26	IC1 - Pin 10	
A3	R2-5M/P5 Pin 5	Force measurement	D27	IC1 - Pin 15	
A4	R1-5M/P5 Pin 4		D28	U1 – Pin 1	Smart switch control
A8	R0-5M/P5 Pin 3		D30	P3-9	Display control
A10	U4-Pin 7	Motor current measurement	D31	P3-6	
A11	U3-Pin 7		D32	P3-8	
A12	U2-Pin 7		D33	P3-5	
D5	IC2 - Pin 1	Enable/Motor speed control	D34	P3-7	
D6	IC1 - Pin 1		D35	P3-4	
D7	IC1 - Pin 9		-	-	-

Table 16. Arduino pin connexions

6.1.3 Components operation

Smart switch – MIC2514Y

His operation is simple: when detecting a HIGH input on pin 1, pins 3 and 4 are connected, so it's closed. And it will be open when 1 is LOW. Pin 2 is connected to ground, and 3 and 4 are, therefore, the pins to connect or disconnect.

Motor driver – L293D

This chip requires two supplies: one for the motors, being the one in pin 8 at 12 Volts, and another at 5Volts for the component, in pin 16, along with 4 GND pins, 4,5,12 and 13. Then, we have one enable pin per motor (pins 1 and 9), where if the voltage is LOW there's no movement, and if it's HIGH the motor shall work. But it can also work with voltages in between, which is possible using PWM digital pins from Arduino. There are also two digital inputs per motor for controlling the polarity (1A-2A and 3A-4A), which can be achieve if one has a high input and the other low, or vice versa. And output pins directed to motors are Y ones, two per motor too (1Y-2Y and 3Y-4Y).

Current measuring – ACS712

Current measuring has been achieved in theory by using current sensor ACS712 which works based on Hall's effect. To measure current it must be placed in series with the target, connecting together pins 1-2 (IP+) and 3-4 (IP-). Pin 5 is connected to ground, 6 is a filter pin recommended to be connected to a capacitor of 1 nF (and this to GND), and 8 to 5V, being at the same time connected to a 0.1uF capacitor. In pin 7 the reading is obtained, with a sensitivity of 185 mV/A for the 5 A model. In our case, with currents of 300 mA maximum the output is quite low. One option would have been to amplify this signal, but ACS712 is a chip able to sense negative and positive currents, being the output 2.5 V for 0 Volts, therefore around 0V when -5A and 5V when 5A. That's the reason it wasn't implemented, due to the fact that if that Arduino can only measure until 5 V in our case, and a useful amplification would have overpassed that value.

Other methods were tried to measure the current. All of them worked on the basis of placing a resistor with a known and low value in series with the motor, so with that data and measuring the drop of voltage in the resistor current could be obtained. The most basic one consisted in using two analogic pins, each one in one side of the resistor, measuring them with Arduino and calculate by code the difference. If the current were in one direction it would work, placing the resistor next to the negative pin (so the voltage is lower), however when changing the current flow, that resistor would be in the part with highest voltage, which is dangerous for Arduino pins. Assembling the circuit in the prototype voltage was around 9-10 in that part, and those pins measure only until 5, so they could suffer and overload and end up broken. In that case the resistor could have higher value, around 15 Ohms. Another studied option was using operational amplifiers, so the value of the resistor was reduced to 1Ohm (being around 1.6 Ohms when measured). First it was tested with the op TL074IN in differential amplifier layout, with R1=R2 and R3=R4, and different relations between those resistors to obtain different gains, but the output voltage wasn't changing, which can be caused by the fact that some amplifiers have a range of operation lower than the difference between their supply values, so if we had a supply of 5 V and GND, the range was between, according to our measures, 1.5-4V. And that depended also on the inputs, being the current less than 50 mA at normal operation, but when grabbing and object, or being stopped, that current increased being able to reach between 330-400 mA. It was simulated in NI Multisim 13.0 but the output was alike.

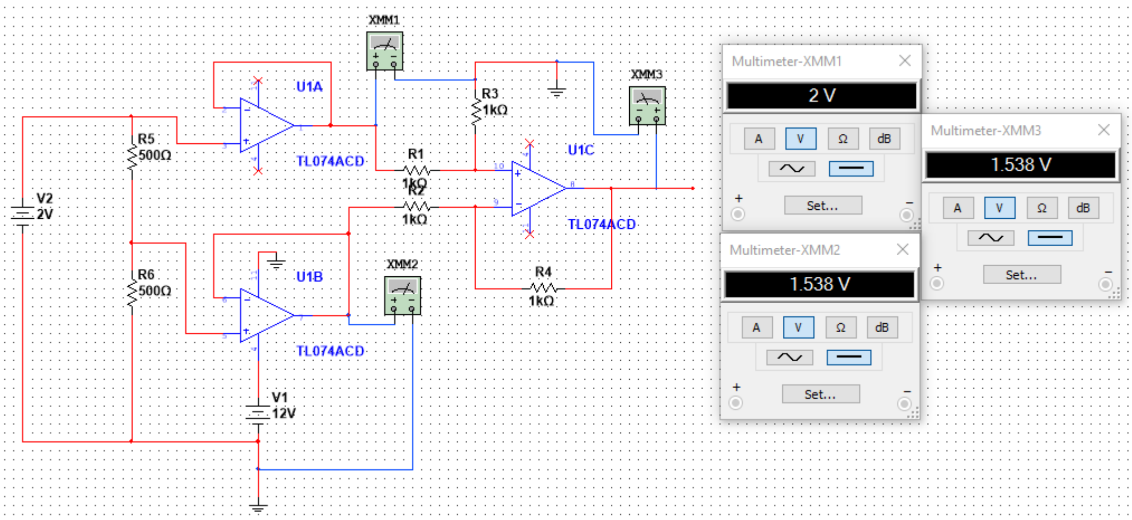

Figure 32.TL074 - Multisim simulation

Even using unity gain buffers, so the current is insignificant, we can see these operational amplifiers don't work properly in such conditions, being the measure in XMM2 1.538 V instead of 1 V, as it should be for this voltage divider. And the difference amplifier layout has issues too. The difference is 0.5 V approx., but it is reading 1.538V in XMM3. As it seems in this case, for low voltages the output is alike.

As a consequence, it was changed to a low voltage model, MCP6041, being used thrice in the measurement too: two of them in unity gain buffer amplifier, so the current drained is insignificant, and the other as a differential amplifier, with the which worked perfectly for voltages below 5 V.

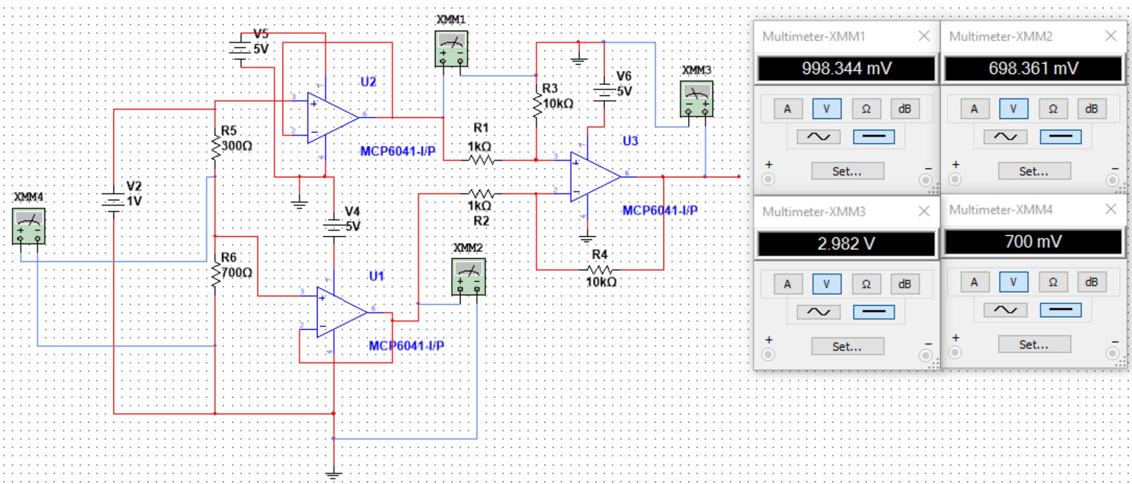

Figure 33.MCP6041.

However, like when measuring only with Arduino pins, the voltage supposed a problem, in this time on the amplifiers, because they would receive a high voltage, 10 Volts, double that their supply (5V), when the current is inverted (negative), so they would worsen quicker, not being a proper sensing system in this case. Sensing in both directions was the main cause that drove us into choosing ACS712 as current sensor.

Force, position and battery measurement

These readings didn't suppose big complications. In all of them, a voltage divider is used, due to their behaviour as variable resistor for position and force (for the battery they have fixed values). So the layout of the resistors would be the following one:

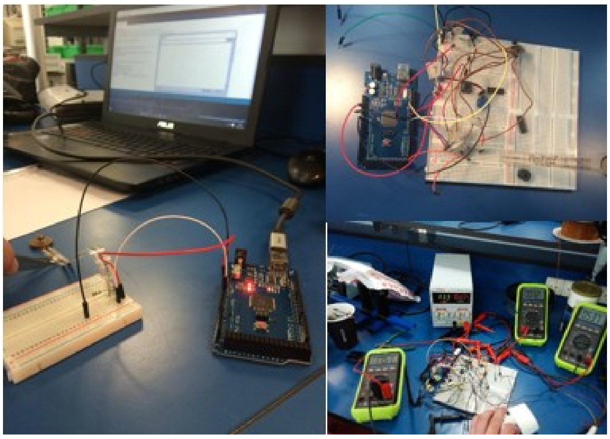

Figure 34. Testing sensors and power supply

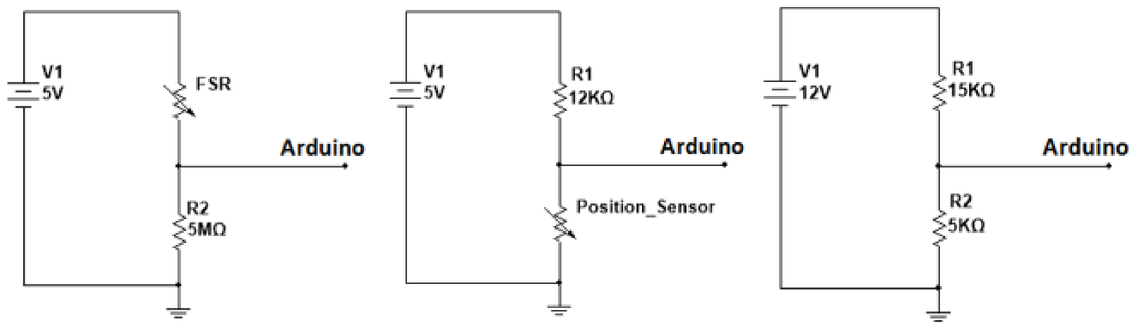

Figure 35. From left to right, force position and battery sensors.

As we can see sensors are placed in different places. Logical thinking for the sensor was the following one: when activated, the output voltage reading should increase. According to that, force sensor should be placed in the upper part of the layout, connected to 5 V. When pressed, its resistance decreases, so in this position the voltage would raise. With the position sensor it's the opposite: when bended its resistance is higher, so it should be connected to ground. The values of the adjacent resistors are calculated for a proper sensing range, so in the case of the FSR (Force Sensitive Resistor), its value when pressing has a wide range, between 21 and 0.8 MOhms (50-1000 grams), so the sensor chosen has a value of 5 MOhms. With the position sensor the range is smaller, between 10 and 14.6 KOhms (Minimum and maximum hand position), being 12 KOhms the value for the complementary resistor.

6.1.4 Programming

Program

The code for the final model would be the following one. A clarification first: this code hasn't been tested due to the lack of the required components, and has been written and compiled in the Arduino IDE, version 1.6.8.

```
//LIBRARIES
#include <LiquidCrystal.h>    //LCD Library

//FUNCTIONS
void settings();    //DECLARING INITIAL SETTINGS FUNCTION
void sensorRead(short unsigned int *pos, int pin1,short unsigned int *forc, int pin2,short unsigned int *cur,
int pin3);  //SENSORING FUNCTION FOR ONE MOTOR
void motorActivation(short unsigned int forc, short unsigned int pos, short unsigned int cur, int pin, bool
*dir, bool *motorEnable);  //SETTINGS FOR ONE MOTOR
void motorPolarity(int pin1, int pin2, bool dir, bool motorEnable);  //POLARITY ACTIVATION FOR
ONE MOTOR
void screen(short unsigned int batt,short unsigned int posi1,short unsigned int posi2,short unsigned int
posi3,short unsigned int forc1,short unsigned int forc2,short unsigned int forc3);

//VARIABLES
unsigned long timer, preTime1=0, preTime2=0;    //Declaration of time parameters
short unsigned int dif1=0, dif2=0, dif3=0;
short unsigned int bat=0,for1=0,for2=0,for3=0, pos1=0,pos2=0,pos3=0, cur1=0,cur2=0,cur3=0;
bool direction1=true, direction2=true, direction3=true, motorEnable1=true, motorEnable2=true,
motorEnable3=true;
LiquidCrystal lcd(30, 31, 32, 33, 34, 35);    //Pins 30-35 are set for the library

////SETUP////
void setup(){
  settings();
}

////LOOP////
void loop(){
   ////Timer////
  timer = millis();
  dif1=timer-preTime1;
  dif2=timer-preTime2;

////READING POSITION, FORCE AND CURRENT////
  if(dif1>=100){
    preTime1=timer;
    bat=analogRead(9);  //Battery level
    //Sensor reading
    sensorRead(&pos1,0,&for1,3,&cur1,10);
```

```
    sensorRead(&pos2,1,&for2,4,&cur2,11);
    sensorRead(&pos3,2,&for3,8,&cur3,12);
  }

  ///////SMART SWITCH///////
  if(bat>613||bat<358||cur1<507||cur1>515||cur2<507||cur2>515||cur3<507||cur3>515)
digitalWrite(28,LOW);   //If the battery is higher than 12V or lower than 7V, or the motors are doing too much force, the smart switch opens
  else digitalWrite(28,HIGH);

  ///////MOTOR ACTIVATION///////
  motorActivation(for1, pos1, cur1, 5, &direction1, &motorEnable1); //MOTOR 1
  motorActivation(for2, pos2, cur2, 6, &direction2, &motorEnable2); //MOTOR 2
  motorActivation(for3, pos3, cur3, 7, &direction3, &motorEnable3); //MOTOR 3

  ///////MOTOR POLARITY///////
  motorPolarity(22, 23, direction1,motorEnable1); //POLARITY MOTOR 1
  motorPolarity(24, 25, direction2,motorEnable2); //POLARITY MOTOR 2
  motorPolarity(26, 27, direction3,motorEnable3); //POLARITY MOTOR 3

    ////Screen////
  if(dif2>=1500)
  {
    preTime2=timer;
    screen(bat,pos1,pos2,pos3,for1,for2,for3);
  }
}

///////FUNCTIONS///////

////INITIAL SETTINGS FUNCTION////
void settings(){
  lcd.begin(8, 2);
  pinMode(5, OUTPUT);
  pinMode(6, OUTPUT);
  pinMode(7, OUTPUT);
  pinMode(22, OUTPUT);
  pinMode(23, OUTPUT);
  pinMode(24, OUTPUT);
  pinMode(25, OUTPUT);
  pinMode(26, OUTPUT);
  pinMode(27, OUTPUT);
  pinMode(28, OUTPUT);
}


////SENSING FUNCTION////
void sensorRead(short unsigned int *pos, int pin1,short unsigned int *forc, int pin2,short unsigned int *cur, int pin3){
    *pos=analogRead(pin1);      //Position reading - Position limits: 500 for initial position and 560 for close position
    if(analogRead(pin2)!=1023&&analogRead(pin2)!=0)*forc=analogRead(pin2);      //Force reading - Force limits: opening with less than 300, holding between 300 and 700, and closing from 700 until the maximum, 1023
    *cur=analogRead(pin3);      //Current reading - Current limits: when closing 519 ard uds, opening 503 ard uds
}

////MOTORS - ENABLE, DIRECTION AND SPEED////
```

```
void motorActivation(short unsigned int forc, short unsigned int pos, short unsigned int cur, int pin, bool
*dir, bool *motorEnable)
{
 if(forc<=300&&pos>500&&cur>507&&cur<515) // Opening position situation
 {
  *dir=true;
  *motorEnable=true;
  int force=map(forc,0,300,250,0);    //Proportional force according to the pressure on the force sensor
  analogWrite(pin,force);   //PWM overt the enable pin
 }else if(forc>=700&&pos<560&&cur>507&&cur<515) // Closing position situation
 {
  *dir=false;
  *motorEnable=true;
  int force=map(forc,700,1023,100,250); //Proportional force according to the pressure on the force sensor
  analogWrite(pin,force);   //PWM overt the enable pin
 }else{
  *motorEnable=false;
  digitalWrite(pin,LOW);
 }
}

////MOTORS - ACTIVATION////
void motorPolarity(int pin1, int pin2, bool dir, bool motorEnable)
{
 if(dir==true&&motorEnable==true) // Opening position situation
 {
  digitalWrite(pin1, HIGH);
  digitalWrite(pin2, LOW);
 }else if(dir==false&&motorEnable==true) // Closing position situation
 {
  digitalWrite(pin1, LOW);
  digitalWrite(pin2, HIGH);
 }else{
  digitalWrite(pin1, LOW);
  digitalWrite(pin2, LOW);
 }
}

////DISPLAY////
void screen(short unsigned int batt,short unsigned int posi1,short unsigned int posi2,short unsigned int
posi3,short unsigned int forc1,short unsigned int forc2,short unsigned int forc3)
{
  static bool screen=true;    //Variable to change display every 1.5 secs between battery values and sensor
values
  lcd.clear();
  if(screen==true){
   screen=false;
   int batConver=map(batt,0,1023,0,20);   //Conversion to volts, in that pin we would obtain 5 volts when
the battery level is 20V
   lcd.setCursor(0, 0);
   lcd.print("BAT:");lcd.print(batConver);lcd.print("V");    //Print battery Voltage
   if(batt>613)   //If the battery is higher than 12 V, this situation is unlikely to happen due to the
disconnection of this sensor with high voltage
   {
    lcd.setCursor(0, 1);
    lcd.print("DANGER");
   }else if(batt<358)   //If the battery is lower than 7 V, this situation is unlikely to happen due to the
disconnection of this sensor with high voltage
   {
```

```
    lcd.setCursor(0, 1);
    lcd.print("LOW BAT");
   }
  }else{
   screen=true;
   short unsigned int cPos1, cPos2, cPos3, cFor1, cFor2, cFor3;
   cPos1=map(posi1, 464, 568,0,9);
   cPos2=map(posi2, 464, 568,0,9);
   cPos3=map(posi3, 464, 568,0,9);
   cFor1=map(forc1, 0, 1023,0,9);
   cFor2=map(forc2, 0, 1023,0,9);
   cFor3=map(forc3, 0, 1023,0,9);
   lcd.setCursor(0, 0);
   lcd.print("P:");lcd.print(cPos1);lcd.print(" ");lcd.print(cPos2);lcd.print(" ");lcd.print(cPos3);
   lcd.setCursor(0, 1);
   lcd.print("F:");lcd.print(cFor1);lcd.print("  ");lcd.print(cFor2);lcd.print("  ");lcd.print(cFor3);lcd.print("
");
  }
}
```

UML

Being the UML diagrams for the same code the following ones:

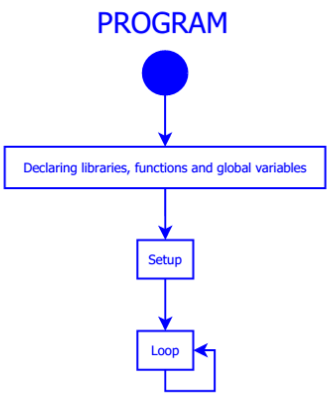

Figure 36. Program UML diagram

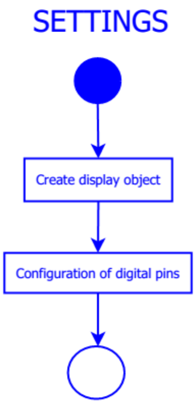

Figure 37. Settings UML diagram

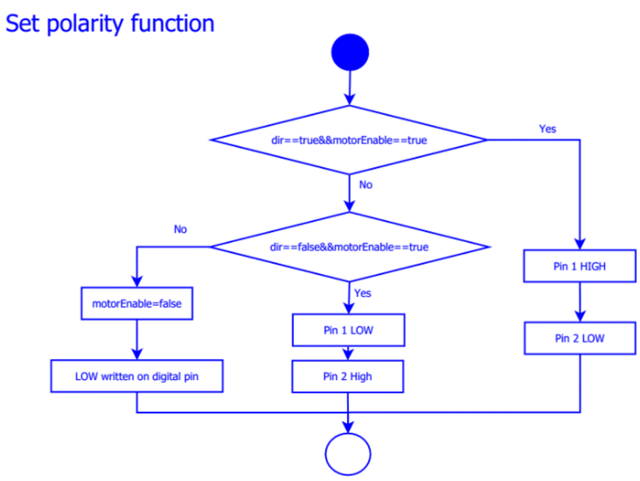

Figure 38. Set polarity function UML diagram

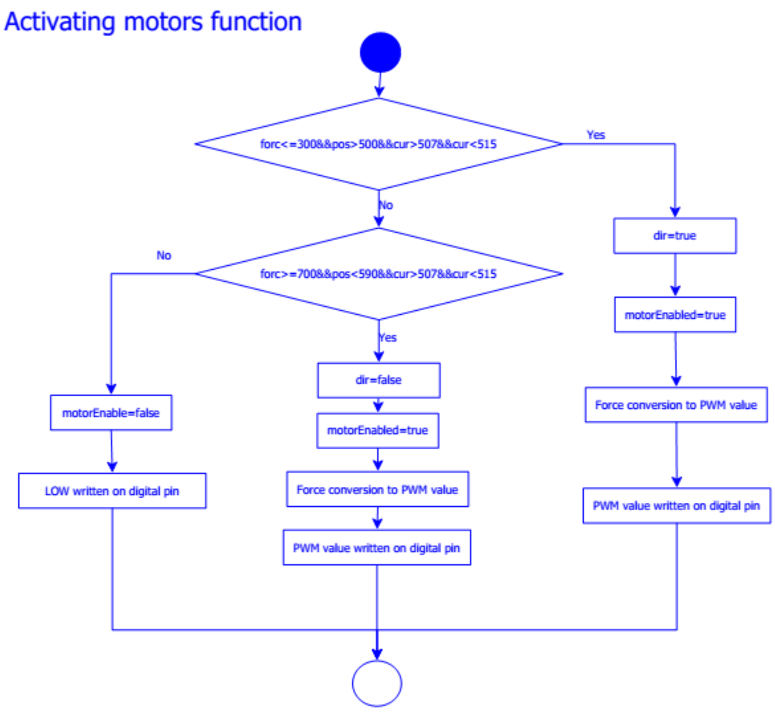

Figure 39. Activating motors function UML diagram

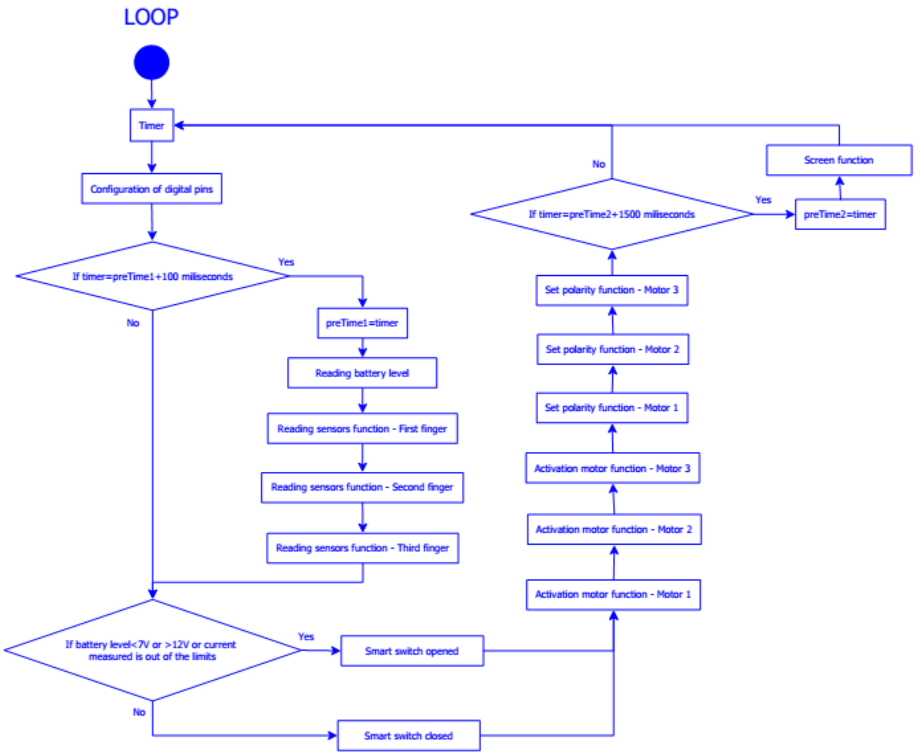

Figure 40. Loop UML diagram

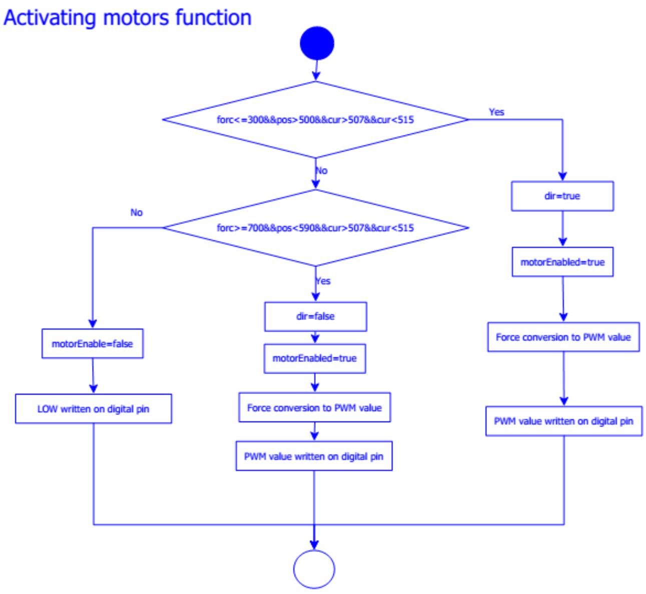

Figure 41. Activating motors function UML diagram

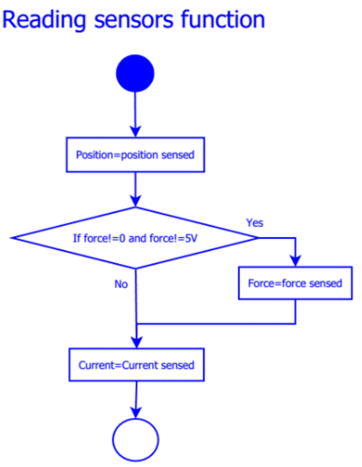

Figure 42. Reading sensors function UML diagram

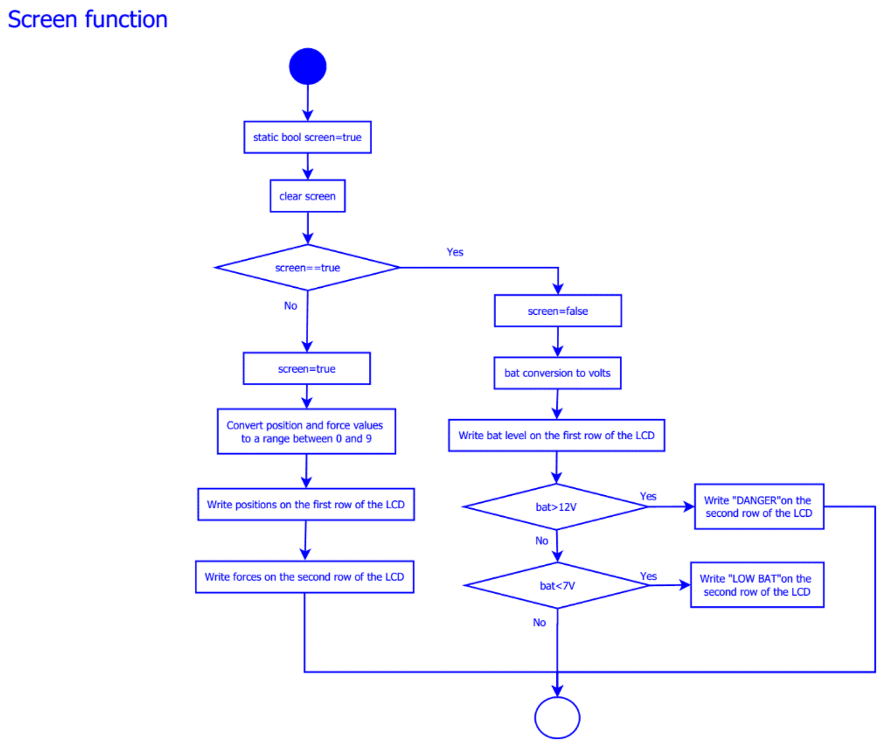

Figure 43. Screen function UML diagram

Program explanation

This code is designed for a final model, which would use the PCB detailed in previous sections. In that code there would be a timer, which would be used for reading sensors and battery level every 100 milliseconds. When sensing there are some differences respecting to the force, because that sensors in really sensitive and sometimes, even if the force is average, detects 0 V or 5 V, so the code is designed to skip those readings.

The smart switch would cut the supply, when the voltage is higher than 12 V, less than 7 or the current exceeded 100 mA, both negative and positive.

Motor activation is done depending on the readings. When a low force (less than 300 Ard uds, 1,46 V), and the hand moved (higher than 500 Ard uds, 2.44V) the hand will close, quicker if it's lower. However, with a force higher than 700 and a position inferior to 560, it will close. Two details must be specified about opening and closing operations, positions are different from the real limits, being the ranger thinner, which implies an additional safety to the user. Also, when the current sensor detects 100 mA (like in the smart switch) there shall be no movement, motor stay still. It may look like an unnecessary part, but in the case the smart switch would fail, and current keep flowing, this measure wouldn't allow operation. If the conditions aren't accomplished, actuators are stopped.

Motor activation is in charge of setting the motor polarity depending on the outputs of the previous phase. Afterwards, the last step in the loop is updating the screen, which happens every 1.5 seconds. Then it changes the displayed numbers, existing two possibilities: in one battery voltage is in the first line, and in case there's overvoltage or under voltages the second line displays a warning message (DANGER for high values, and LOW BAT in the second case). The other possibility shows sensor values, specifically force and position, all of them, with values from 0 to 9, so they are more intuitive. In the first row positions, and forces on the second.

6.1.5 Wire management

In each finger there are two sensors. These sensors have to be connected to the Arduino. The same for the motor, these are connected to motor drivers on the Arduino pcb. At last there is also the display mounted on the forearm. This one also needs to be connected to the PCB. A graphical representation of the wire is given in the image below.

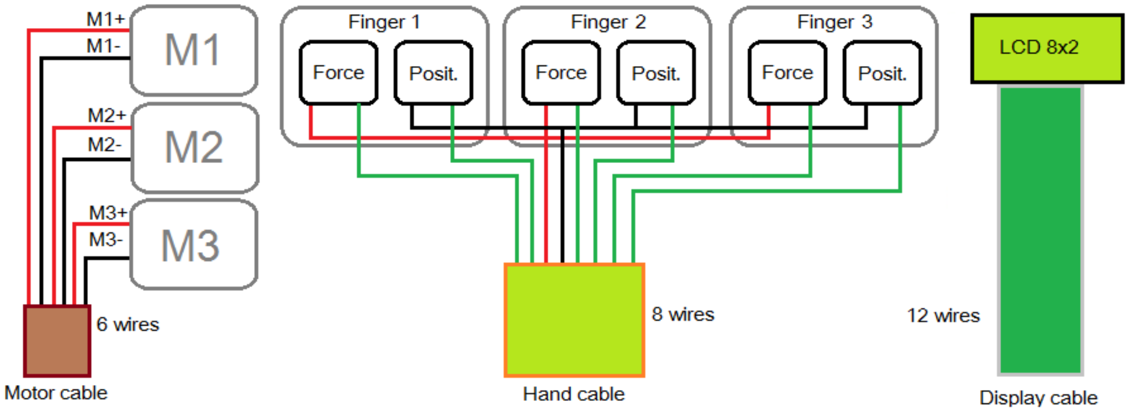

Figure 44. Wire management schema

The cable that arrives at the control unit will have a connector. This connector will connect at least 26 small cables to the pcb. As it can be seen on the right picture the connector is the already known as D-type parallel connector.

Figure 45. D-type connector

On the next image is shown a 3D model where the cable management should be connected through the forearm to the fingers

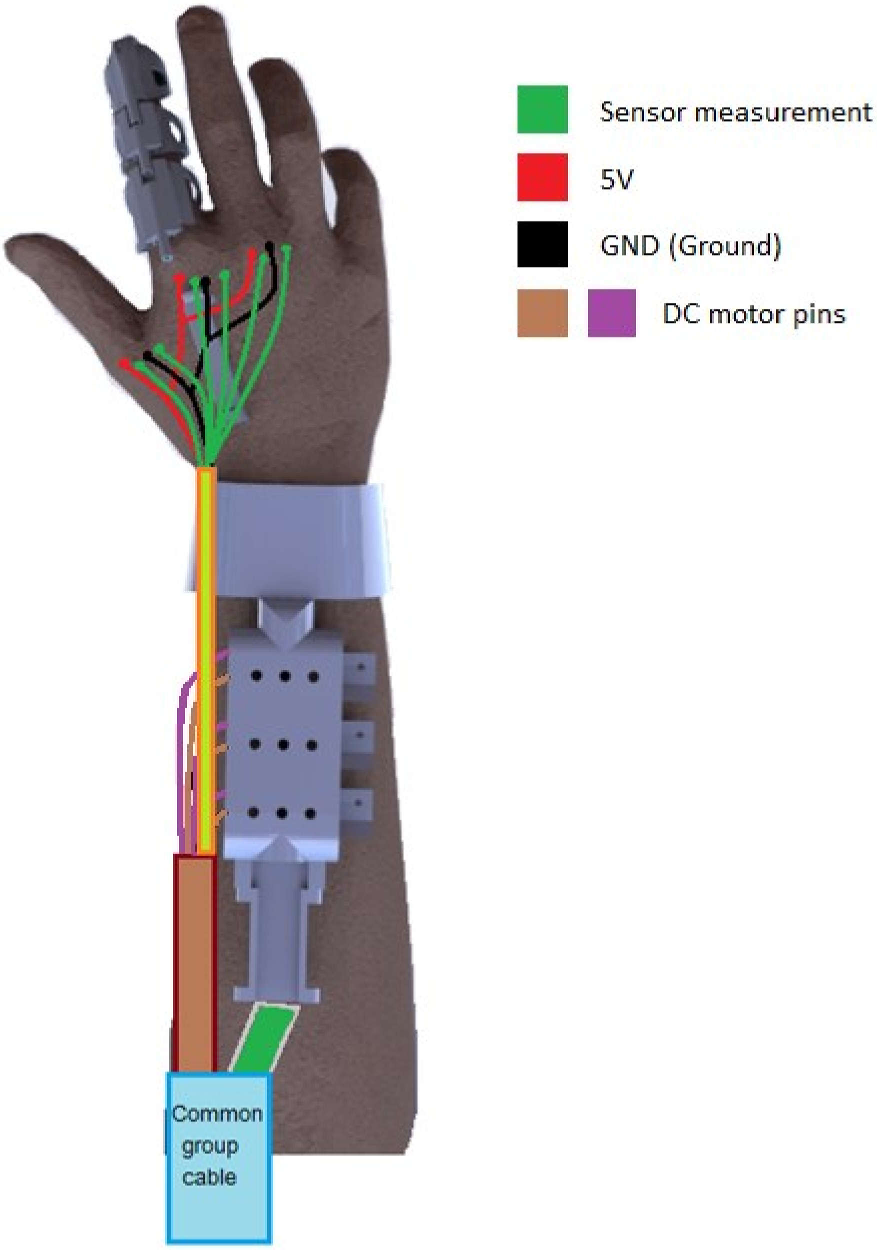

Figure 46. 3D model wire management

The next image shows one cut true finger, together with the sensors and wires running true the finger.

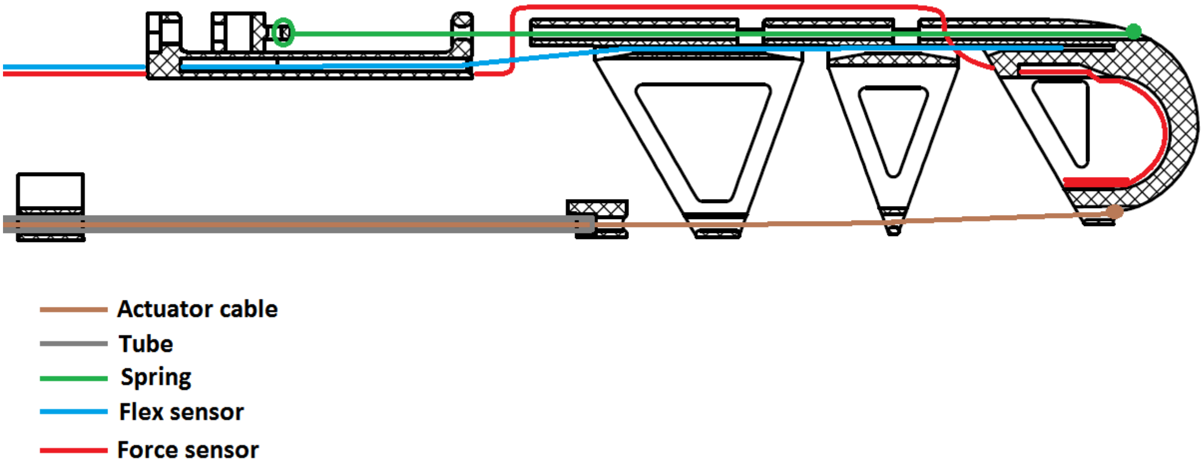

Figure 47. Finger frame cut out

6.1.6 Battery

Power usage:

These values are measured in normal working conditions. @11V

Component	Consumption(mA)
Arduino + interface	150
3 motors	150
Motor drivers	20
Amplifiers	7,5
Battery reading	1
Motor start-up peaks	5
Grabbing	7,5
Total:	341mA

Table 18. Amperage power consumption.

Table 17. Commercial battery used.

In the table below different batteries are compared.

Battery	capacity (mAh)	Weigth(g)	size(mm)	lifetime (hours)
Ansmann 11.1V Wire Lead Terminal Lithium-Ion Rechargeable Battery Pack	2600	145	74x55x19	7,6
	5200	270	72x56x38	15,2

Table 19. Comparison of batteries.

6.2 Electromechanical

6.2.1 Gear motor

The gear motor is used as actuator, its moves the fingers by pulling a cable. The cable runs over a spool, the gearbox attached to the motor rotates this spool. This type of actuator is robust and powerful because the rotational energy of the motor is not converted to a linear movement.

The motor is a standard dc motor with brushes. The motor works on a voltage between 3v and 24v.

The gearbox is directly connected to the motor. It has a gear ratio of 1:250, therefore it has a lot of torque at a low rpm.

Since we could not get much information from the motor manufacturer, we tested the motor our self. We did this to know the power usage and characteristics for different load situations.

We hang weights on the wire of the motor, the motor was fixed to the table. The different weights are used to simulate the load as torque.

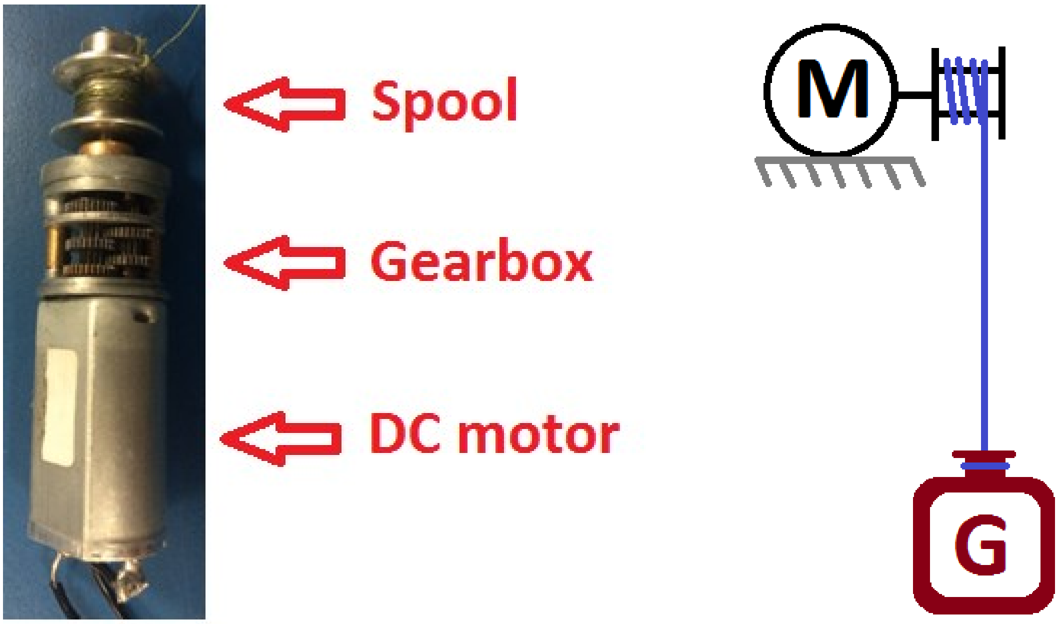

Figure 48. From left to right, winder motor parts and winder motor schematic testing.

<u>DC motor characteristic</u>

Current (mA)	Voltage (V)	Power elektr (W)	Weight(g)	Torque (Nmm)	Time (s)	Speed (mm/s)	rpm	Power mech (W)	η (%)
21	5	0,105	0	0	41	11,95	28,55	0,00	0,00
22	5	0,11	10	0,4	44	11,14	26,60	0,00	1,01
22	5	0,11	20	0,8	44	11,14	26,60	0,00	2,02
23	5	0,115	50	2	45	10,89	26,01	0,01	4,73
26	5	0,13	100	4	47	10,43	24,90	0,01	8,02
32	5	0,16	200	8	48	10,21	24,38	0,02	12,76
48	5	0,24	500	20	54	9,07	21,67	0,05	18,90
74	5	0,37	1000	40	67	7,31	17,47	0,07	19,77

Legend:

Motor spindel diameter (mm):	8
Travel (mm):	490

Table 20. Dc motor characteristics.

The first graph shows:

- When load is applied the rpm decreases linear

  This makes the movements more natural.
- When load is applied the current increases linear

This relation is useful for this application. When a person wants to grab something the motor load is going to increase, this means that the current is going to increase. This increased current is measured by the control board, for further use.

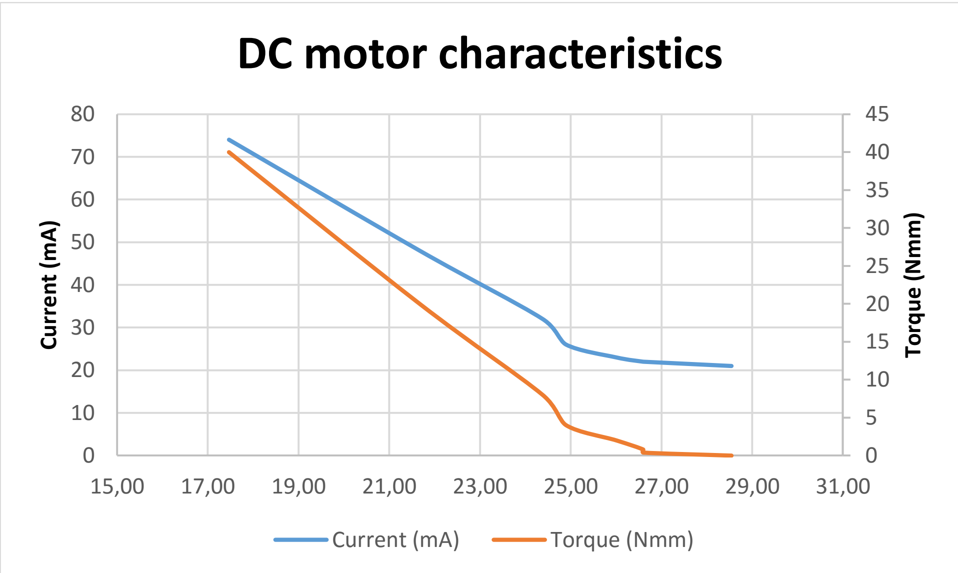

Figure 49. DC motor characteristics (torque-current).

The second graph shows:

- The higher the load, the higher the efficiency

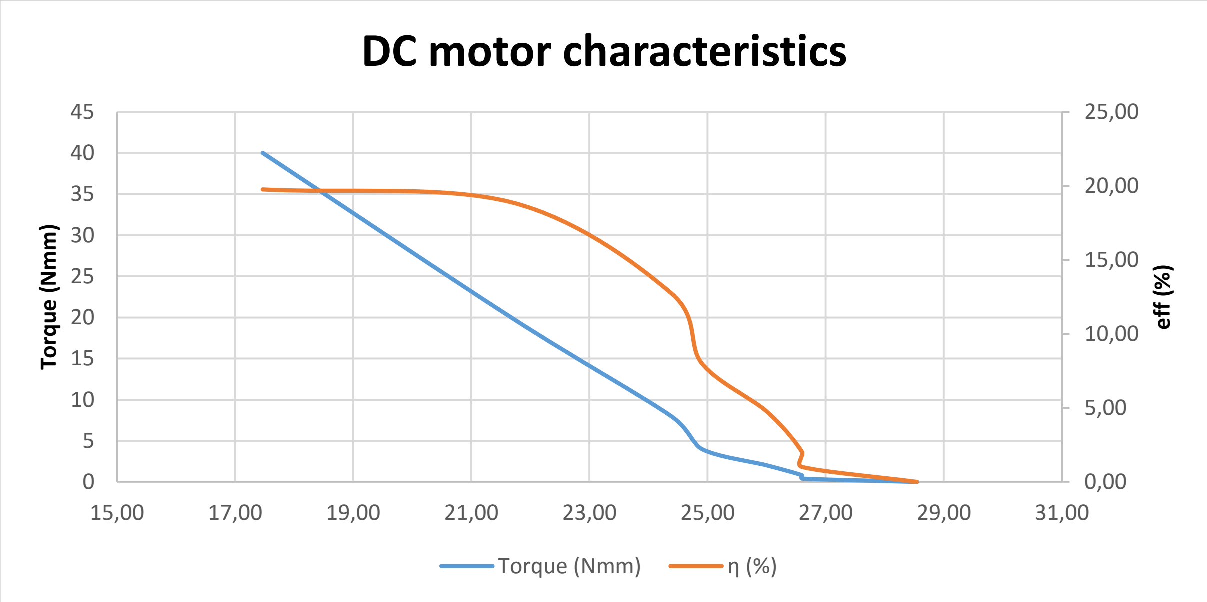

Figure 50.DC Motor characteristics

6.3 Structure

The image below shows the different parts of the system working together.

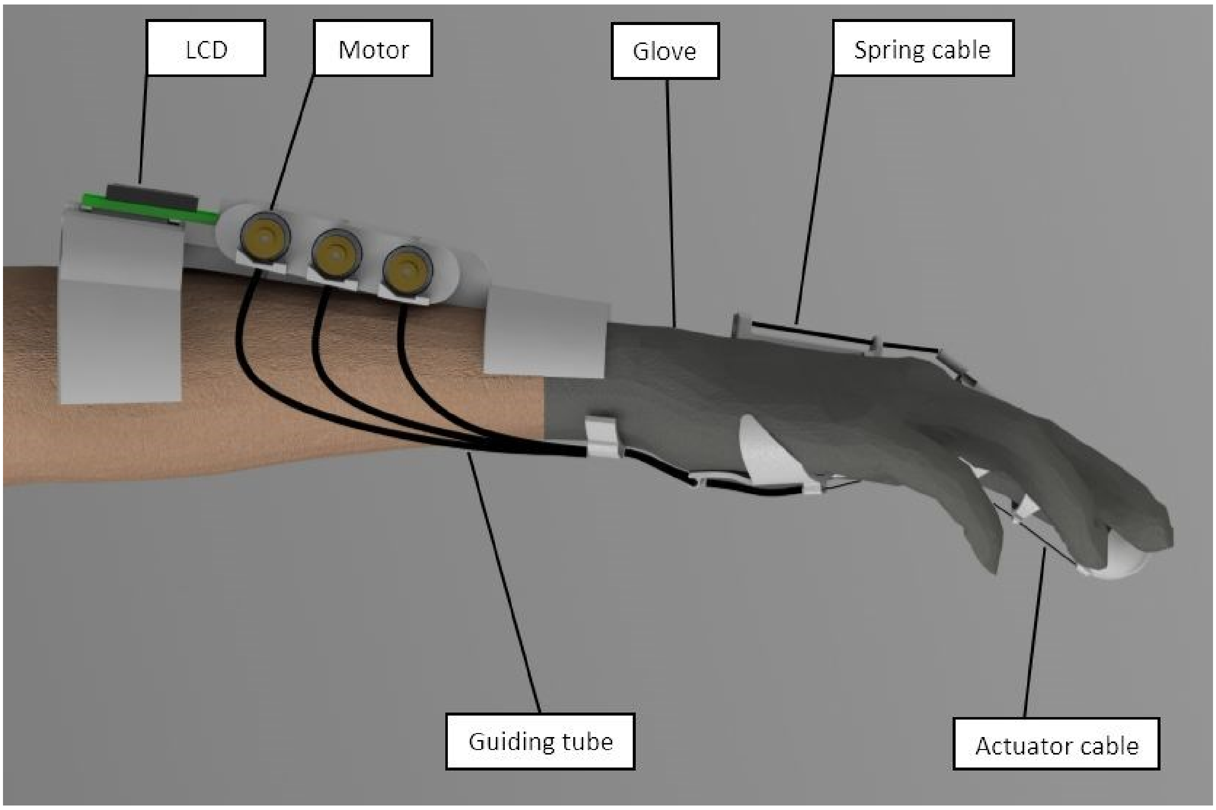

Figure 51.Arm layout.

The motors wind cables on a spool, this creates a force in the cables. This force is transported true the cable by guiding it in a tube. After running true the tubes, the cables run true the different finger parts and are at the end connected to the finger tips. The force in the cables result in a momentum on the finger joints, which creates a closing movement.

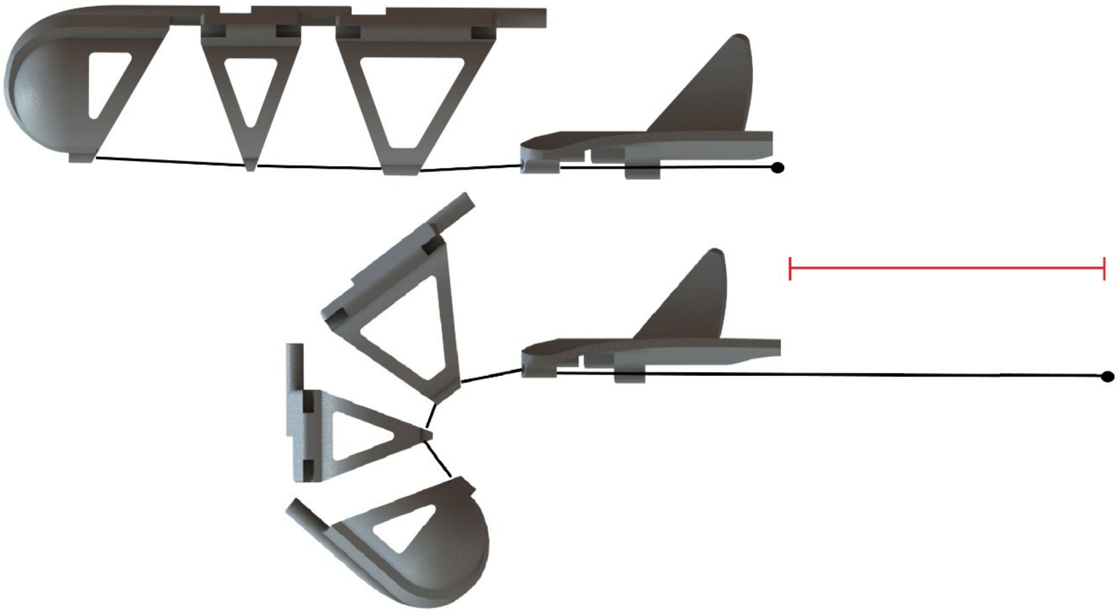

Figure 52.Finger frame movement.

When the motors unwind the cable. The force in the cables reduces till the force of the spring cable is high enough to stretch the finger again.

6.3.1 Actuator cable

The actuators that control the fingers are situated in the arm of the user. This means that the movement of these actuators has to be translocated. In the exoskeleton hand this translocation is created by a cable. This cable is fixed to the spool of the gear motor, when the spool starts turning, the motor starts pulling the cable. This pulling action makes the finger closing.

The cable is an important part of the device, it is the connection between the actuators and the fingers. It should be able to handle the high loads when working and at the same time it must break when loads are unsafe. In this case the wire is one of the safety options.

The diameter of the cable is related to the strength. Thicker cables are usually rated for a higher load. But it has to be a thin cable in order to fit true the hand structure. And the cable may not be too thin because a thin cable can cut true the structural parts or even cut true the users skin.

Another important property of the cable is that it may not have stretch. This would create lag in the controls of the exoskeleton hand.

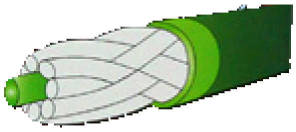

Figure 53. Braided nylon wire

The cable used in the exoskeleton hand is a braided nylon cable. It is mostly used by anglers because of it high strength in combination with small section. This makes it perfect for this application.

6.3.2 Technical drawings

The technical drawings can be found in the appendix.

For all of the manufactured parts of the exoskeleton hand there is a technical drawing. These drawings show the parts in an iso view. On the technical drawing only the dimensions that change with the measurements of the user are shown. These dimensions are important because they describe the specific parts. More dimensions are useless since the parts are 3D printed and therefore only need the .stl file.

In the future the cad drawings will be build up with relations between the dimensions. This allows the company to fill in just a few measurements (shown on technical drawings) in order to create the fitting part. This will save them a lot of time because they do not have to change all the complex shapes.

6.3.3 Production methods

The components for the exoskeleton hand can be divided in groups: the electronic components, the mechanical components and the components to purchase. The production of these components is independently. They only have to be put together at the end of the manufacturing process. This chapter is divided in the same way. There is a part about the manufacturing of the electronics and a part about the mechanical components. The list of components can be found in the price calculation.

Electronics

All the electronic components that are not included in the micro controller are soldered on a PCB board. This board is made following the PCB design as shown before.

Mechanical components - Structural parts

These structural parts are the connection between the actuators/controls and the users body. This means that the dimensions of these components are very much depending on the user's body.

The components are also very complex, they have many rounded shapes and small details. This makes it very hard to produce these parts with conventional production methods. Therefore we decided to produce all these structural part by 3d printing. 3d printing has advantages and disadvantages.

Advantage

- Flexible with dimensions (no molds)
- Complex shapes are possible
- Cheap
- Customizable parts
- Range of materials

Disadvantages

- Poor finishing quality
- Lower mechanical strength
- Slow

The 3d printer used at VIA is the Ultimaker 2+. These are the specifications for the print of all the components needed for the exoskeleton hand:

Quality	**Nozzle diameter(mm)**	**Time (hours,minutes)**	**Material (grams PLA)**
Low	0,4	25,54	164
Normal	0,4	48,27	189
High	0,25	157,3	180

Table 21. PLA timing and weight printing specifications

Tests show that the difference between high and normal quality is notable. Furthermore the working cost of a 3d printer is mostly related to the material used. Therefore the best option is to print the parts in high quality.

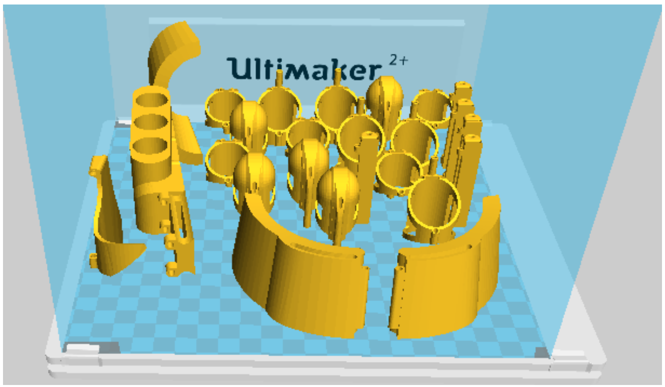

Figure 54. Completely exoskeleton hand pre printing

Because of the fact that the structure of the hand is completely 3D printable the customer can print its own hand structure.

On the website of our company there would be an online and free application. Here everyone can insert the measurements of his hand and arm. These dimensions are processed by the app and at the end the person can easily download the .stl files of the complete hand structure needed for the exoskeleton hand. This person can afterwards print his exoskeleton hand parts at home or wherever he wonts. This also means that the user can easily modify the hand structure as they prefer. Of course the customer could also order the parts from the use, so they get there quality exoskeleton ready to use. On the Image below you can see an example preview of the web application.

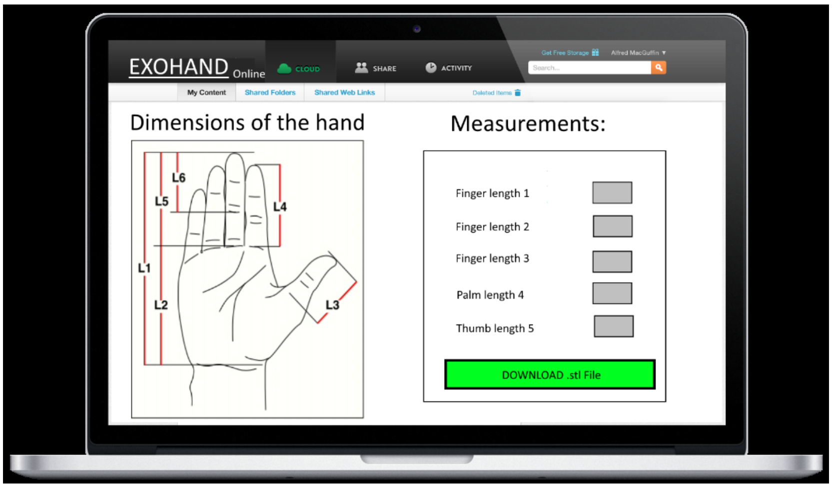

Figure 55. Exoskeleton hand webpage

We have also designed a tool for the user, our service centre and partners to easily measure there hand. (See picture below) This is because it is difficult to make these measurement. Because the human body is no rigid part, it is important to know how to measure.

Figure 56. Finger standardized measurement tool

6.3.4 Glove

To make the exoskeleton hand easy to put on and take of the structural parts are glued on a glove. This glove keeps all the parts on the right place but is at the same time flexible to make it possible to bend the joints of the finger. This glove is an essential part of the exoskeleton hand since it’s constantly in contact with the person.

Using a glove can give some issues. The glove covers the hand completely and this means that the glove has to be a skin friendly material. Since the user is going to wear this glove all day, it is important that it suits al seasons and that It stays comfortable in any daily situation.

6.4 Results

6.4.1 Speed and force

The calculation of the force and the speed of the finger can be found in the appendix.

The table below shows the results.

Close time	0,65s
Close force (fingertip)	0,5kg

Table 22. Closing speed (theoretical time) and force

6.4.2 Controls

In order to give the user a product that can really help them with daily tasks, it is important to have easy controls. The Controls of the exoskeleton hand should be designed in a way that they manage to control the movements without a need for the user to think about the exoskeleton hand.

The exoskeleton hand will be controlled by using 3 types of inputs.

Sensor type	Measured value
Force sensor	Users intention
Flex sensor – flexible potentiometer	Position of the finger
Current measuring	Delivered force

Table 23. Sensor measuring value

Force sensor

This sensors measures the force delivered by the finger tip of the user on the frame of the exoskeleton hand. This force is converted in to a certain action of the actuators. This conversion is done by the program of the Arduino. The measured force results in one of the three possible outcomes as explained in the graph below.

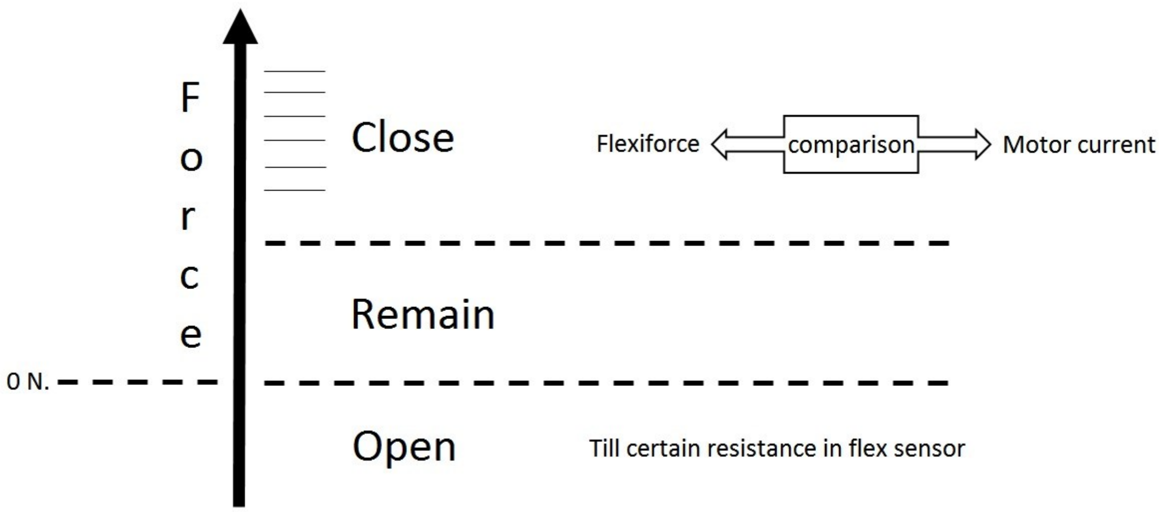

Figure 57. Range of forces for closing and opening.

The force sensor turned out to be difficult to calibrate. The measurements are unstable and need to be cleaned in order to make them useful. Furthermore there were also problems with the dimensions of this sensors.

Flex sensor

The flex sensors gives the arduino the position of the finger. This position is used to stop the motors when the fingers are fully closed or open the fingers just till they reach the stretched position. The flex sensor turned out to be perfect for this application. It fits nicely in to the fingers and gives good and reliable information.

Current measuring

The current sensing option was very promising because it is a cheap option and it eliminates the need for more expensive and complex force sensors in the hand. Unfortunately there were some issues with this option. Test showed that it is not easy to measure the low current true the motors in an accurate and reliable way. This type of measuring needs some refining in order to work properly.

6.4.3 Weight

The weight of the exoskeleton hand is one of the most important factors. An exoskeleton hand that is to have cannot be used for daily tasks. In this project many decisions were made based on the weight of the certain options. In this topic the weight of the final design is calculated as precise as possible. For some of the parts such as the electronics this is rather an estimation because it is hard to find all the information necessary to calculate the weight. Afterwards the total weight can be compared to the criteria's mentioned before.

Mechanical components			
Component	Weight (g)	Amount	combined weight (g)
Fastners and extra's	50	-	50
Glue	1,1 g/ml	1ml	1,1
Neoprene coating	6100/m²	10cm²	61
PTFE tubing	4,5/m	0,5m	2,25
Winder motor	30	3x	90
Elastic material wire	2/m	0,5m	1
Glove	50	1x	50
Nylon actuator wire	0,8/m	2m	1,6
3D print parts	168	1x	168
Total			424,95g

Table 24. Mechanical components combined weight.

Electric components			
Component	Weight (g)	Amount	combined weight (g)
Connectors (26pins)	10	2	20
Arduino casing	50	1x	50
Rechargeable Batteries	270	1x	270
PCB + components	50	1x	50
Arduino mega	37	1x	37
Wire (26pin wire)	5kg/100m	3m	150
Alphanumeric LCD	20g	1x	20
Flexi force sensor	2	3x	6
Flex potentiometer	2	3x	6
Total			609

Table 25. Electric components combined weight.

Exoskeleton hand	
Part	Weight (g)
Mechanical components	424,95
Electric components	609
Total device	**1033,95**

Table 26. Total weight.

6.4.4 Price

Component	Description	Unit/Quantity	Price	DKK
Mechanical part			€ 62,52	kr. 464,49
PTFE Bowden Tubing 100mmm	Tube for covering the wires	5	€ 6,58	kr. 48,85

Winder motor		3	€ 12,00	kr. 89,16
Elastic material wire		0.5m	€ 0,07	kr. 0,48
Glove		1	€ 1,31	kr. 9,73
Nylon actuator wire		3m	€ 0,50	kr. 3,68
Forearm long part	PLA plastic	1	€ 15,78	kr. 117,25
Forearm small part	PLA plastic	1	€ 13,01	kr. 96,66
Fingers parts	All five fingers with 3 parts of each	5	€ 10,47	kr. 77,79
Hand part	All parts	1	€ 2,81	kr. 20,88
Electronic part			€ 293,14	kr. 2.178,00
C1,C3,C5	1nF	3	0,11871	0,882
C2,C4,C6	0.1uF	3	0,15666	1,164
Diode	5V, 11.16V	1	0,19381	1,44
Fuse	2A	1	0,42799	3,18
R	5MOhm	3	9,65814	71,76
R	12 Kohm	3	0,04684	0,348
R	15 Kohm	1	0,46568	3,46
R	5,11 Kohm	1	0,46568	3,46
R	220	1	0,01427	0,106
MIC2514Y	Smart switch	1	2,11978	15,75
ACS712	Current sensor	3	14,463	107,46
L293DNE	Motor driver	2	6,49798	48,28
Switch	Power smitch	2	0,71332	5,3
Display	LCD 2X8	1	7,31898	54,38
Force sensor	25 Lbs sensor	3	69,1332	513,66
Position sensor	10 Kohm	3	38,9233	289,2
PCB-102x55		1	4,9004	36,41
Batteries	11.1 V 5.2 Ah	1	64,9152	482,32
Additional components		1	26,9179	200
Arduino Mega	Controller	1	45,6851	339,44
Total price			€ 355,65	kr. 2.642,49
Total price + shipping			€ 426,78	kr. 3.170,98
Assembly hours		8	€ 240,00	kr. 1.783,20
Final price excluding shipping			€ 666,78	kr. 4.954,18

Table 27. Price table.

7 Marketing environment

An analysis of the marketing environment will permit us to know what will be the sales conditions of our product, the exoskeleton hand. We will study the macro-environment and then the micro environment.

7.1 The macro environment

Also called PEST analysis, the macro-environment permits to know more about the environment of the product and the market. Different factors need to be treated like political, economic and ecological ones, as well as social and cultural factors and technology. These six factors will permit us to understand the market where our product will be sold.

Figure 58. PEST analysis.

[1]

7.1.1 Political factors

In Denmark, the medical devices, such as wheelchairs, glasses, pacemakers, dental crowns, but also prosthesis are not authorized by the Danish Medicines Agency. They must have a « CE » accreditation to use them[2]. Having this mark is important to the Danish legislation. In fact, while medical devices are not permitted, an authorization from the European Community will permit them to allow it in the country.

[1] http://www.dreamstime.com/royalty-free-stock-photo-pest-analysis-diagram-image23211115
[2] http://laegemiddelstyrelsen.dk/en/

The act n° 1046 of 17 December 2002 concerning medical devices talks about two points which are the authorization of clinical investigation and fees. The Danish Health and Medicines Authority (DHMA) defines a clinical investigations[3] as “a study in human subjects undertaken to assess or verify the safety or performance of a medical device.”

The exoskeleton hand is a new medical device on the Danish market and require so an authorization by the DHMA and must contain CE marked devices.

The Commission Regulation n° 207/2012 of 9 March 2012[4] gives some rules concerning the utilization of electronic on medical devices. In fact, it is important to have some safety instructions concerning their utilization. The user must be aware about that.

7.1.2 Economic factors

The general incomes in Denmark is high and represents around 250,000 DKK for men and 175,000 DKK for women in 2014 according the Danish Statistics.

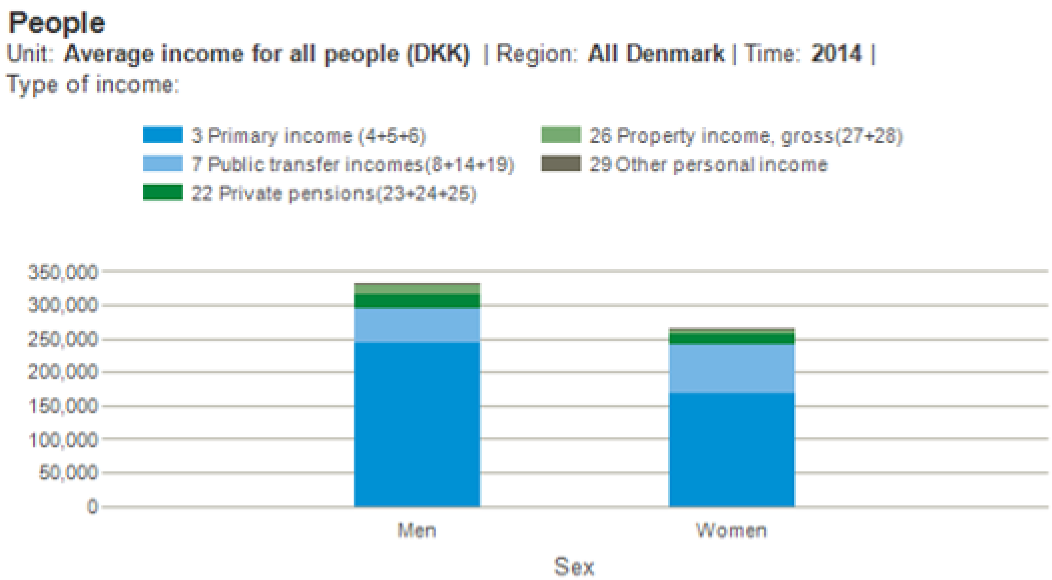

Figure 59. Average income in 2014

5

The lifestyle of people and life expectancy become healthier and longer with the advanced technology of medical devices and researches in diseases. In Denmark, according to the statistics, the life expectancy to new born in 2015 is around to 78,6

[3] file:///C:/Users/Candice/Downloads/Clinical_Investigation_of_Medical_Devices_21012013_rev1.pdf
[4] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0207&from=EN
[5] http://www.dst.dk/en/Statistik/emner/indkomster/personindkomster

years old for men and to 82,5 for women. We can see a progression since 2010. Moreover, the number of death people is the highest between 80 and 90 years old. There were 16 588 deaths which represents the highest rate. Life expectancy from a year to another one become longer, so elder people live longer and need some medical devices to help them daily and to become more independent.

Life expectancy for new born babies
Unit: -

	2010:2011	2011:2012	2012:2013	2013:2014	2014:2015
Men	77.3	77.9	78.0	78.5	78.6
Women	81.6	81.9	81.9	82.7	82.5

Table 28. Life expectancy of new born from 2010 to 2015.

Deaths
Unit: **Number**

	2011	2012	2013	2014	2015
Total	52 516	52 325	52 471	51 340	52 555
0-9 years	278	259	258	274	260
10-19 years	112	90	102	84	84
20-29 years	234	226	207	229	233
30-39 years	498	415	410	435	355
40-49 years	1 495	1 405	1 317	1 273	1 226
50-59 years	3 700	3 673	3 577	3 376	3 386
60-69 years	8 170	8 238	8 089	8 074	7 802
70-79 years	12 311	12 261	12 162	12 281	12 751
80-89 years	16 756	16 709	16 939	16 071	16 588
90 years +	8 962	9 049	9 410	9 243	9 870

Table 29. Different age group of death people from 2011 to 2015

7.1.3 Ecological factors

The ecological aspect of products became important to customers in the last few years. They want a product eco-friendly which fit with the nature. In the medical sector, it is more difficult because of the durability, reliability, materials, and also of the product. However, customers care about that. Actually there is not some eco-friendly medical devices but some parts on it are.

7.1.4 Socio-cultural factors

Having a disability is something difficult for the man. The human feels apart from others because he knows that he is not like everyone else. Moreover, the expression of others on its disability will not help him in society. However, people pay less attention to people with a disability and help them, they integrate easier in life. The mentality of people changes in the last few years.

We can also add that a lot of researches, and medical materials exists nowadays in the aim to improve quality life of handicapped people.

7.1.5 Technical factors

Actually we are living in a world where we want to improve quality's life of everyone and in particularity people with disabilities. Different products are existing and technology doesn't stop and continue to improve. Each product is doing in the aim to have some lighter materials, with a good quality, with different functions and being attractive to the customer.

7.2 Conclusion

After an analysis of the macro environment of the country, we think that the product may have a chance to be successful after having considered all different aspects of the PEST analysis. There are even political considerations regarding the investigations for the Danish Health and Medicines Authorities. The exoskeleton hand will allow people with a lack of strength in their hand or arm to use it again and feel some sensations that they can do actually.

Next, we analyze the micro-environment.

7.3 Micro environment

The analysis of the micro-environment is important to assess the chances of success of our product in the market and compare it with those being developed by others or available in the market.

7.3.1 Customers

The exoskeleton hand is for people with a disability with their arm or hand, who lost the functionality of it due to an accident, a born or even a degenerative disease. The market in Denmark is relatively low. It represents less than 20% of the population according to a physiotherapist. This percentage represents approximately the number of people with a born disease, a degenerative illness. We also have to take in account the fact that few of those persons have a problem with their arm or hand.

7.3.2 Competitors – Porter's five forces model

The Porter's five forces model permits to understand the strengths of the current and future competitive position of a product. The five forces include the potential entrants, buyers, substitutes and the suppliers. Sometimes, another force is added to the list above; this new force is the government.

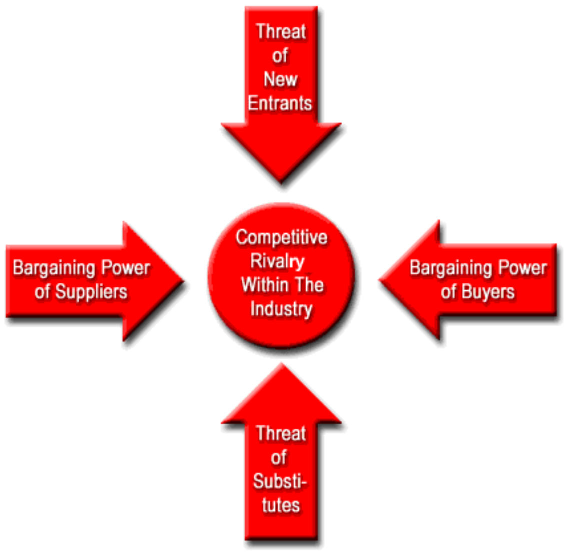

Figure 60. Porter's five forces.

The new entrants

It is important to analyze the threat that new entrants into the market may pose because a new company may change a lot of things in the market. This is why we have to analyze the entry barriers and the rivalry determinants.

A company has to analyze different issues for determining if its product can have enough sales for covering all costs.

Economies of scale

First of all, we consider the economies of scale of the exoskeleton hand, that is, its place in the market. In fact, there is actually very few competitors. The others companies are focused on exoskeleton for legs, to help people to walk again. Furthermore, there are several prototypes of exoskeleton hands tested.

Brand identity

The brand identity of the company is important. Large companies have been in the market for a long time and have conquered a lot of customers by the quality, reliability and services of their products. Being a new company on medicine devices, can be seen as an advantage but also as a drawback. Indeed, we are unknown from specialists in hospitals and clinics. Our new product is the first one on the market and can have some prejudices on it. Nevertheless, it is a new company and it is a way to show that we want to improve quality's life if people with disabilities with some new products on the market.

Rivalry determinants

Industry growth

Actually, medicine researches is still developing in many ways. The aim is to find some new treatments for trying to cure some important diseases. In the exoskeleton's market, some products already exist and are already on the market. A lot of prototypes are tested. Companies want to improve their product, innovate.

Competitors

In the exoskeleton's market, some products are already available and have been tested before on patients. Those exoskeletons are only for people handicapped.

Here are some prototypes of exoskeleton hands concerning the assistance.

Martinez et al

In New Jersey, a power-assisted exoskeleton has been designed to help the pinching and grasping motion of people with decreased hand functionality caused by diseases. The company designed an under-actuated cable-driven exoskeleton with some passive and active extension mechanisms. The hand function with three actuated fingers.

Hasegawa et al

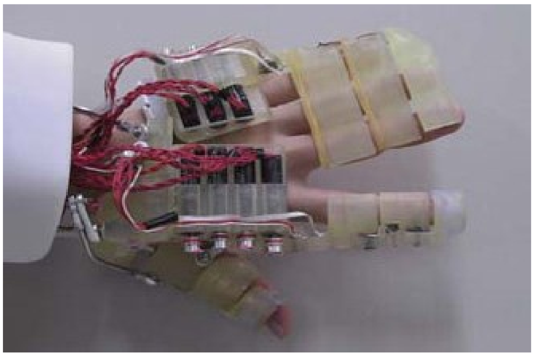

Figure 61. Hasegawa et al prototype

This exoskeleton hand has been developed to assist with hand and wrist functions. There is a cable-driven mechanism mimicking human finger motion driven by tendons. One of the advantage technically of the product is that the device controls each joint independently. It is used to stimulate the compliance variation of a human finger according to the grasping force exerted to maintain grasping stability.

In and al

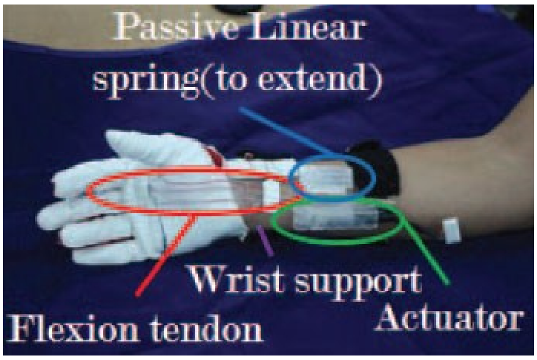

Figure 62. In and al prototype

This exoskeleton hand is a glove type to assist disabled people. There is an under actuated cable-driven mechanism attached to a glove. A cable exerts a flexion force on each finger while the extension force is provided passively by a spring.

Buyers

__*Bargaining leverage*__

The bargaining power of buyers is important. Their negotiation on price and sales conditions will permit to determine the profitability of the product.

If in the market there are not enough potential customers and interested ones in a product, the bargaining power of buyers is an important tool for a company because it has to employ a higher negotiation level than other companies. Concerning the exoskeleton hand, one main problem exists, it is the number of potential customers. The percentage of Danes with a disability with their hand due to a traumatism, an accident or even a degenerative disease is low. Moreover, the company must create some products which fit with the different diseases of patients to cover the most people of possible must also to create a product enough sophisticated to let them use their hand without or less pain as possible.

Another point is important which is that the company is new on the market. That's why the company must do an exoskeleton hand adapted to the patients with disabilities to their hand but also must have a big emphasis on after-sales services and maintenance of the product.

Moreover, actually on the market, there are no other exoskeleton hands. It is an opportunity for us to innovate. However, bigger companies can after copy the model and then do one more sophisticated. Being a small company has the disadvantage that the research is not that high and take more time than a big one due to the number of employees and the qualification of each.

The objective of each company is to have its own customers and keep them, to have their loyalty through us.

Concerning retailers which are clinics, hospitals and specialists, it can be complicated for them to agree on the product, to know the different characteristics, the reliability of the product but also of the company. The exoskeleton hand is a new product on the market even if there were already some exoskeletons in prototypes.

Buyer information

Before buying a product, a customer must have some information about it, how it works, and eventually about its special features. A seller has to provide all those information to the potential buyer.

Each exoskeleton hand will have a users' guide and a notice for the maintenance which is important for the durability of the product. An after-sales service will be in place with a telephone number, but also a guide on the website's company.

Substitution products

Nowadays, there's no substitution products for people with a disability with their arm and hand. There's no products which permit them to make it works. However, some doctors like physiotherapists help patients to move their muscles to avoid a loss of too much muscles.

Differences between the substitution product and the product

The exoskeleton hand has for aim to permit to people with a lack of strength in their hand to use it again. Indeed, generally this kind of people had an accident, a degenerative disease or even a born disease. A physiotherapy won't be able to help the patient to grab, pick an object. There are no prices for exoskeleton hand prototypes. However, the price is much lower than others exoskeletons on the market which are for the legs. It is less sophisticated and works only for the hand.

Impact of brand identity on quality/ performance

Our company is not well-known in the market but our product has a good quality. We want the best for our customers; we want to simplify our customers' daily life, to help them to do some daily tasks. Since we are not currently known in the market, we have to attract customers to our product and all its benefits.

Buyers' profit

Our buyers are all medical centers like hospitals, clinics but also some specialist's doctors working with patients who can't move their arm. A main profit for them is to have a new product, something revolutionary in this field, something never been done before. The product has the advantage for the patient to help them to use their hand for taking, picking some objects, which without it couldn't do all those things. In addition, the exoskeleton hand will permit to handicapped people to use their arm. The product will be done on measure for each patient and will be easy to use.

Moreover, the product will be launch also as an open-source and some people who know more than normal users, can improve the product.

Suppliers

Suppliers power

The suppliers' power depends on their negotiation abilities with firms concerning the cost and quality of the raw materials necessary for the manufacturing of the exoskeleton hand. When they are product-specific and few, companies have to choose a good supplier in terms of quality and price. This is particularly so, because the costs associated with, for example, the raw material transport increase with distance. Another factor to consider is the number of potential customers; the larger the number of customers in the market, the larger the number of companies that will try to be the largest seller. Finally, one should also take into account the cost associated with a change of supplier because, in general, there is an exclusive contract between a company and its supplier and, therefore, a change to another supplier requires that the company pays a lot of money for it.

7.3.3 Conclusion

Porter's five forces allow us to know what are the different environments closely linked to the company. Since exoskeletons are not more promoted by clinics, doctors, they are not more affordable for possible patients, companies already on the market don't specialize their exoskeletons for the upper body, and there are not too many barriers to introduce our product in the market.

7.3.4 Distributors

The exoskeleton hand will be available on hospitals and clinics. Moreover, some physiotherapists can have it and will be able to help the user with it.

However, the product will be available on the website of the company. You will have to order it, assembly or non-assembly.

7.3.5 Conclusion

From the analysis of the macro-environment and micro-environment, we can deduce the opportunities and threats that our exoskeleton hand will encounter in the market. Those analyses permit the company to improve its product and mitigate its drawbacks; it will also allow to assess the market opportunities for the exoskeleton.

Opportunities

Opportunities are external factors that a company may use to its advantage. As discussed above, there are some companies specialized in exoskeletons but only for people who can't walk. Wanting to explore the market on exoskeleton but for people with disabilities with their hand and arm is an opportunity for us to find a place of this market.

Moreover, the exoskeleton hand will permit to patients to grab, pick some objects, things that they can't do everyday with their handicap. A possibility to do some daily things with their two arms and hands will be possible.

The product will develop in a country where the number of elder people is high and will permit them to be more independent. They have with the age some osteoarthritis and it is difficult for them to move them articulations. That's why the product is a good opportunity for them to use their hand again with less pain as possible.

Threats

Threats are current and emerging external factors that can challenge a company's performance.

Several threats exist for the exoskeleton hand. The first one will be the existence of others exoskeletons' companies. Those companies are bigger, have a good investment in research and development compared to our company, which is new on the exoskeleton market. Indeed, actually their products or prototypes are well advanced in technology. As soon as our product will be on the market, they will be interested by our product and will want to build also an exoskeleton hand. With a bigger company, more money, investment in research and development, that will be easy for them to have a better product than us and to sell it.

Some exoskeletons hand prototypes are existing and are more developed than us. They can critic our product easily and that can have a negative impact on the future sales.

8 Strategic actions

8.1 Main strategies

8.1.1 Mission

The mission of our company is to help daily people with a disability to their arm or hand, to help them to have an easier life but also to permit them to grab or pick some objects.

8.1.2 Vision

The vision is to integrate the exoskeleton hand to people with a lack of strength in their hand and arm to help them to have an easier life. The company is based on strong values from the Danish society concerning healthcare.

8.1.3 Target group

With interviews that we did, we could target more for which kind of people the exoskeleton will be for. First of all, people having the most kind of problem with their hand and arm, are old people due to their age, but also adults who had some strokes, so a paralysis, and children, for both gender.

We target more in particularity, people who want to be more independent in their life. In fact, having a deficiency in their arm is a handicap for them. They cannot do all they want and generally need someone to help them.

8.1.4 Interview

The aim of those interviews is to have more information about the exoskeleton hand, different aspects to take in account in the construction, the potential customers that the Danish market represents.

The interview is divided into different parts. The first one concerns questions about the market, the potential customers in Denmark, and also more information about diseases with a lack of strength. The second part is about questions for the mechanical part, try to understand how the hand function, and how they can build the best product with the knowledge that they have. The last part permits to know the opinion of the physiotherapists on the exoskeleton hand, our product on the Danish market.

Part 1: Market information

What is the age of people having the most kind of problem?

In a general answer, different physiotherapists said that will be elderly people but also children. This can be due to different diseases like a cerebral paralysis, some rheumatoid arthritis for old people but also some strokes which will go through a permanent apoplexy. An operation due to an apoplexy might have some pains, for example in the shoulder in function of the movement done and the sensibility.

What is the percentage of people having a lack of strength due to an accident, to a degenerative disease or born one in Denmark?

In Denmark, the percentage will might be around 20% of people.

Actually what is it doing for those kind of people having a strength deficiency in their arm, hand?

Nowadays, there are not a lot of advanced materials to recover the strength. There are some specialists like physiotherapists. They will manipulate the core, the sensible part and help us to recover. For the arm, they will do some exercises on the hand, the forward arm and also the shoulder. Another way exists which is some electrodes that you put on the zone that you want. Those electrodes will stimulate a zone of muscles, for example the shoulder. The muscles will have to be contracted and will make work the zone without any efforts, without any pain. Concerning the lack of strength in the hand, some exercises that physiotherapists do, are for example a small ball to press and release.

Do you think patients will wear it for helping them daily?

It is difficult to answer to this question. That will depend of each patient, of their age, what they usually do in their life, how they need to use their two arms. An important factor to take in account is the usability of the product. if it is quite complicated, people and especially old people wouldn't use it. The exoskeleton hand must be easy to use, to be employed by everyone, every age group.

Do people with a lack of strength are looking to bad way to others? Do they feel apart to others because of their handicap?

It is relative. That will depend of each individual. People won't maybe pay attention to this. They may see that someone has a problem but won't go further.

Concerning the price of the exoskeleton hand, what should be approximately the price?

The price will depend of the quality of the product, of the number of time of people will use it, so to the functionality. For an exoskeleton hand used few times per week, the price can be between 200 000 and 300 000 DKK. However, if the product is not enough researched and used only few times per year, that will cost only a thousand Danish Krones.

Part 2: Mechanical part

What are the most common movements that people do during a day?

People with a lack of strength in their hand complain the most about grabbing and picking some products.

What is the maximum weight for a hand system?

The lightest it is, the better will be. If the patient has a problem with their hand and/or arm, the product should not be heavy. He will have some problem to wear it.

300g per finger is enough for the exoskeleton hand which is represent a total of 1.5kg.

For how long the battery of the system should last for one day?

The situation for each patient is different. Using their hand too much can be tiring for them. In generally, the battery should last 8^{H}.

How many times should the product have an obligatory maintenance?

Once per year is a good deal and three if it is necessary. More maintenance on the product will discourage the patient to buy it. That takes time and too much maintenance can make the customer think that it is not a reliable product.

Part 3: Opinion on the product

Do you think this exoskeleton hand will have some success in Denmark?

According to a physiotherapist, the exoskeleton in general will have success in few years in the world. Actually, he doesn't know. The technology is not maybe enough advanced and exoskeletons need more researches.

What do you think about the idea?

The idea for all physiotherapists is a good idea. That will permit to people with disabilities to do more things, to don't be stop by their handicap.

Those interviews help us to have more information concerning the product that we want to sell, the market but also about more knowledge on this field that we didn't have. That help us to take into consideration some facts that we didn't thought and which are important. Their vision on our project was important because as professional they can tell us what do we have to improve and for which reasons but also on the future of the product in the market.

8.1.5 Competitive strategies

"Competitive strategies" is a tool which permits to know what kind of strategy the company should adopt about their products by considering the market and the product's price. By using Bowman's strategy clock, we can define a better strategy for the exoskeleton hand.

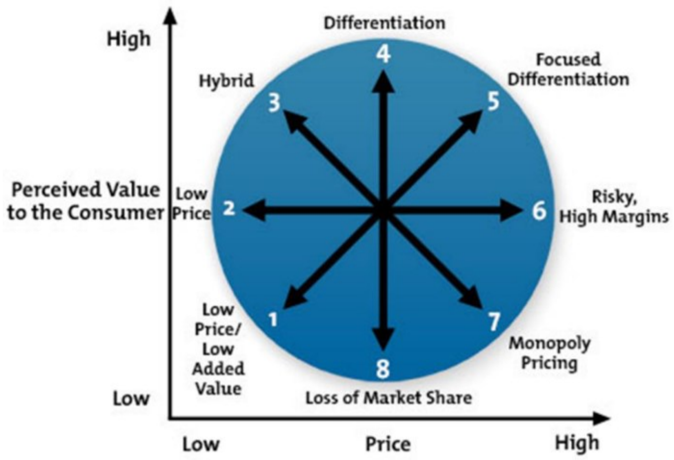

Figure 63. Bowman's strategy clock.

For the exoskeleton hand, we should use a focused differentiation strategy. The product is completely new on the market. People may have heard about exoskeletons and can find in it a good idea. However, an exoskeleton hand as saying before, will help people with a lack of strength to use their hand again. Handicapped people arrive to do some daily tasks without it. They can might not see the advantage, opportunity to have it. Moreover, the price of the product is not that high. That's why a focused differentiation strategy fit the most with the product.

As illustrated in the next diagram, exoskeletons are currently under development, only two exist on the market and there are much more prototypes existing as exoskeleton for legs or for hand. The only products on the market are not well-known from the public and from the potential customers.

We can see on the next diagram, that's why the exoskeleton market is only at its beginning of its development and is representing at the introduction stage of the product life cycle. The exoskeleton hand is also in the introduction phase but lower and need to be improve in the time. Those kind of devices last a long time, almost during an entire life. The number of product replace is very low, almost 0%. The replacement will depend of the age of the person. If it is a child, the product will maybe need to be replace. We can also add that the number of sales will increase in the next year, with the development of those devices and their accessibility.

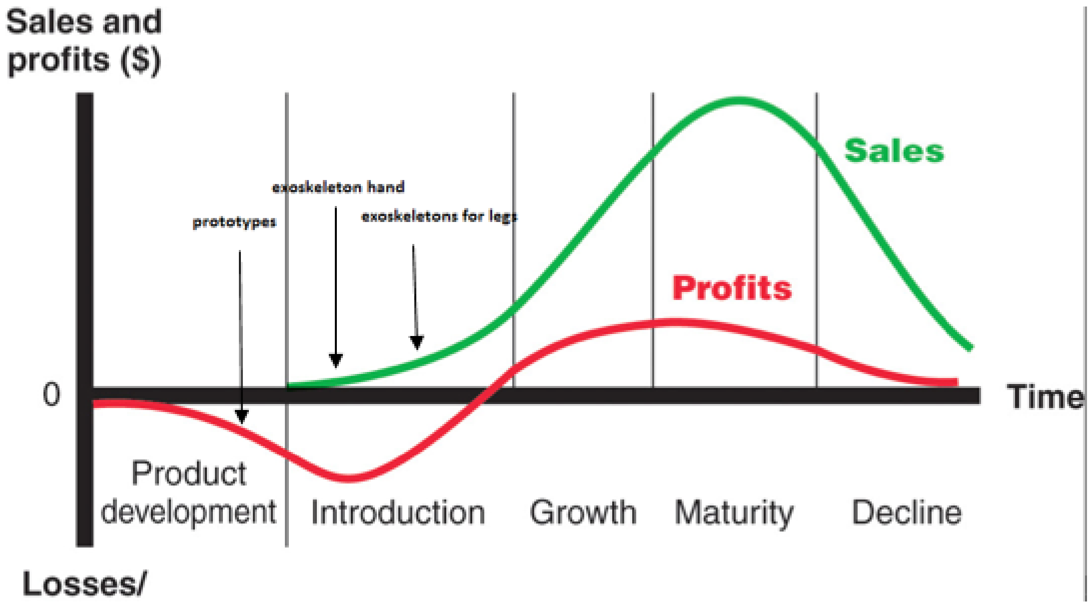

Figure 64. Product life cycle of exoskeletons and exoskeleton hand.

The General Electric model is a portfolio model that consists of two mains characteristics which are the attractiveness of the market and the competitive strength. Compared with the Boston Consulting Group's portfolio model, the General Electric one is more detailed. In the ladder, each characteristic is divided into three phases: high, medium and low as shown in the next figure.

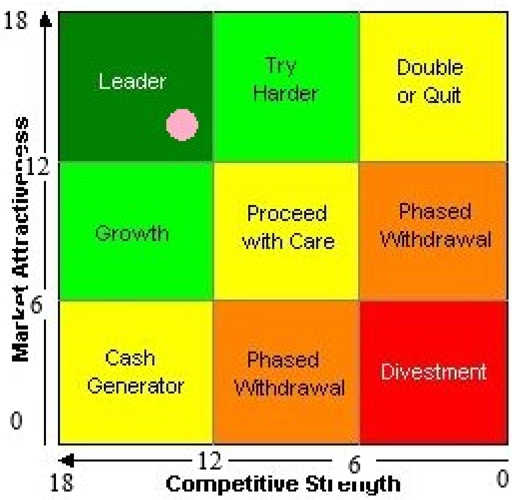

Figure 65. General Electric Model for the exoskeleton hand.

We will give a mark between 0 and 3 for each points of both characteristics in order to place the exoskeleton hand in the General Electric Model. The first characteristic that is market attractiveness can be divided into the following items: the size of the market, growth rate, profit margin, competition, technology, waste reduction and environment.

In order to use the General Electric model for the exoskeleton hand, integer marks ranging from to 0 to 3 are granted to each item of each characteristic and the results are shown in the next two tables.

Different points	Mark between 0 to 3	Justification
Market size	1	The market of the exoskeleton hand is small. People handicapped don't know this kind of product for the moment. They are not enough informing about those devices to help them daily.
Growth rate	1	The growth rate of the exoskeleton hand is not so high. The market size is not big and a product like this lasts a lot, even a whole life.
Profit margin	3	The profit of our product will be high. A product like this costs few thousands

		euros and the material costs few hundreds euros.
Competition	3	There's not a lot of competitors on the exoskeleton market. Only two products are available for patients. No one does some exoskeleton hands.
Technology	2	The technology of our product is not the best due to our competences and knowledges. However, a product like this is one of the latest existing on the market.
Distribution	3	The distribution of the product will be in different place in Denmark and will facilitate the access to different customers.

Table 30. Different points take in account for market attractiveness.

According to the table, the total mark on the attractiveness characteristic is 13, with a maximum of 18 and a minimum of 0. This means that on the vertical axis, the exoskeleton hand is on the leader stage just above the growth market on the market attractiveness scale.

The second characteristic to take in account is the competitive strength. In the next table, we can find the different points which help us to know where the exoskeleton hand is on the General Electric Model. Here are the different points: market share, product/ design, place, price, promotion, R&D

Different points	Mark between 0 to 3	Justification
Market share	2	On the market there's not a lot of competitors and the others exoskeleton are still to a prototype phase.
Product, design	3	The exoskeleton hand is done with a glove, customizable.

Place	3	The product will be available in hospitals, clinics and specialists. It will be also available on the website to order it.
Price	2	Not that high.
Promotion	1	It is hard to promote a medical device for such a small market. The promotion will be essentially to our direct retailers.
R&D	2	The product will be done with the latest technology on the market and the knowledge that we have which can be quite restricted.

Table 31. Different points take in account for competitive strength.

With this table, we can see that the total in to 13 on 18. That means that on the horizontal axis, the exoskeleton hand figure in the leader case, near the “try harder” one.

Those two tables show that our product will be leader on the market and have its chance to be successful by the potential customers.

8.1.6 Conclusion

Behind the mission and vision of the company, different strategies must be adopted concerning the price and target group for the exoskeleton hand, as well as the market. The target group for the company is in priority people with a lack of strength in their hand or arm, from adults to old people but also some children. A strategy of differentiation that emphasizes a new lifestyle concept may be used for marketing the exoskeleton hand in the market.

8.2 Marketing mix

Marketing mix is also called 4P's (product, price, place, promotion) and consists of four analysis tools for the promotion a product.

8.2.1 Product

Our new product, the exoskeleton hand will permit to people with a disability in their arm and hand to grab, pick some products. The aim is to help them to have an easier life, to use again their hand. With a system of cable on each finger, the patient will be able to move them again and grab, pick some objects. The exoskeleton hand will work with a battery. The customer will have to charge it and could use it during the day.

The glove will be customizable: different colors will be possible. Customizing it, the patient will have the impression that the exoskeleton hand is an integral part of its body. The product will become essential in its life.

The product will have some obligatory maintenances. The first year will be take in charge by the company, and the customer doesn't have to pay, then the second year, he will have to pay only the half. After the third year, the maintenance will be full in charge by the customer.

The customer can order it on different places: in hospitals, clinics, specialists but also on the website. On the website, it is possible to order the product in kit. The price is lower and the user can improve it.

The exoskeleton hand presents some strengths and weaknesses.

<u>Strengths</u>

The strengths of a product are internal characteristics that can help a company to reach its selling objectives.

The first strength of the product is the possibility for people with a disability to their hand or arm to move and use it to take or pick some daily objects. The product helps patients to recover their strength but also for people who can't recover it.

Being on a market quite new, using the latest technology is an important strength. This kind of product require the best development of the product for the customers to help him in the best way.

The product will be available also in kit. People who feel able to build it or even some close relationships can do it. It is cheaper than the normal price. Someone interested in the product can work and improve it to have a more efficient exoskeleton hand.

The design of the product is an important aspect. The patient won't have an exoskeleton hand in metal but a glove to put. The visual aspect doesn't be neglect because the exoskeleton hand must be an integral part of body's patient. That's why it will be possible to customize it in different colours.

The body part in plastic is done with an organic plastic called PLA: polymer polyactic acid.

Another strength of the exoskeleton hand is the system which works with a battery to charge. The patient just has to charge during the night and will be able to use during 15hours in continue.

Weaknesses

The weaknesses of a product are the internal limitations that could interfere with a company's ability to achieve its objectives.

One of the first weaknesses of our product is the fact that our company is new on the market and have to find its place on it. The company must be known by its customers which are clinics, hospitals and specialists.

Our product needs to be improved and a large part of the mechanism isn't hidden. It is visible for the user and can be dangerous for him.

The price of the exoskeleton hand for retailers is 11 200 DKK which is not too high due to the different functions, the quality, durability of the product. The body part is in plastic and can be do some allergies to the user or cannot be last a long time.

Moreover, being a new and small company, the product can have some difficulties to develop the product but also to promote it. Indeed, that requires time, employees, money and technology adapted. A product under developed won't have its chance on the market even if there's not others exoskeleton hands. The quality and the price won't match together.

We can also add, that our company is not the first one on the exoskeleton market. There are some bigger companies specialized in exoskeletons even if they only do some exoskeletons for legs. Our new product on the market can be disadvantaged in front of those.

8.2.2 Price

To determine the price of the exoskeleton hand three items must be taken into account: customers, competitors and costs. We call this strategy the 3C's. The first C is about customers. It determines the maximum price that they are willing to pay for the exoskeleton. With a price too high, the potential customers won't be able to pay it, but with a price too low, they will ask themselves about the quality and the reliability of the product and of the company. That's why we have to choose a price in adequation with the quality of the product.

Here is a table with different costs' strategy possible to use for our product.

	PRO	CONS
SKIMMING	More the product will be on the market, more the price will decrease and more potential customers will buy it.	Small target group and medical devices.
SUBSTITUTE	There's no substitute to the product. We can choose a price. However, we have to take into consideration the price of exoskeletons for legs on the market to have an idea.	Existence of only exoskeleton for legs which is different in term of material, technology.
COSTS PENETRATION	High and fast market share	Lower margin on the product. Good quality? Adapted to medical devices ?

Table 32. Pro and cons for different costs' strategies.

The second C corresponds to the competitors. The price of our product should match with the price of our competitors already on the market. We don't have some direct competitors in Denmark and the only competitors existing are competing on exoskeletons for legs.

The third C stands to costs. For selling a product, there is a minimum price to have if the company doesn't want to lose some money. This minimum price corresponds to the costs of the necessary materials to have.

To compete with exoskeletons on the market, the price of our product will be 20 000 DKK for customers and 11 000 DKK for retailers. Since its manufacturing cost is approximately 9 000 DKK, the profit for selling it to a retailer will be about 9 000 DKK. When launching the product into the market, some discounts will be applied especially regarding those related to the colours of the glove. In addition, different payment periods can may be used for different retailers.

8.2.3 Place

The exoskeleton hand will be available for patients in different places. First of all, hospitals and clinics can propose to their patients with a lack of strength in their hand the product. They are the best retailers for the company. Usually people had some strokes, or degenerative, born diseases, so they first go to the hospital to be diagnosed. Then there are also some specialists like physiotherapists who can help people to recover their strength with the exoskeleton hand.

The product will be also available on the website of the company. The customer could order it also in kit.

8.2.4 Promotion

Promoting a medical device is different that promoting a product with a target group bigger than this one. That's why, the best way to promote the exoskeleton hand will be in magazines, newspaper and internet. There are also some conferences who are important to promote the product. Those communication tools will directly target people who want to learn more about this new device, like doctors, patients, or their family, friends.

8.2.5 Conclusion

Based on the data provided so far, we believe that the time is right to launch the Ifridge into the market

9 Communication

The communication of a product has three different goals. The first is to let the product be known. The second aim is to provide means so that the product is associated with an image and a brand. The last goal is concerned with the behavior of consumer that attracts people to buy it even if they not need it.

There are two types of communication: media communication and out-of-media communication. The out-of-media communication concerns the promotion of the by other ways than media. We will see the different media and out of media tools interesting for the exoskeleton hand.

9.1 Media communication

The media communication consists of all the available means to promote a product, such as television, radio, press and internet.

9.1.1 Internet

Actually, Internet is everywhere and takes a lot of place in people's life. That's why, when we want to promote a new product on the market, it is important to use this tool. That's why, for promoting our exoskeleton hand, our company will promote the product on their website. That will permit to our customers, clinics, hospitals to have more information about it but also to propose and to sell the product to their patients in order to help them daily.

9.1.2 Press

With those this way of communication, we can target more precisely people. Indeed, some journalists form specific magazines can do some articles about this new, revolutionary product. Moreover, there can have some articles in newspaper, to inform readers about those new products. The target group will be different, however, it is important to be inform about the new medicine technology on the market. They will be aware about it and that can interest themselves directly or even someone that they know.

9.2 Out-of-media communication

The out-of-media communication has been developed to promote sales and more recently for the direct marketing. The out-of-media communication is a way for targeting customers, stimulating sales with special offers, and creating and improving relationships with the customers. We won't focus on special offers but on how to promote the product and improve the relationship with hospitals, clinics and doctors.

9.2.1 Exhibitions

The advantage to do organize an exhibition is that we can invite the number of people that we want, who can be interested in our product and show them how it works, the different advantages. Doctors can see the product and can have their own opinion on it, share with others specialists.

9.2.2 Meetings

Doing some conferences and meetings are important. Some doctors from a city, a hospital or a clinic are together and it is a way to be in a small community and to present the product. doctors can ask some questions about the product, how it works and the company will answer them. The aim is to show the exoskeleton hand, to promote it, show the advantages of the product for patients.

9.3 Conclusion

The communication part of a company is important for promoting a product. Different ways will be used to let our product be known to our possible retailers including internet, press, meetings and exhibitions.

10 Financial

10.1 Budget

The budget is important for a company because it allows it to assess its sales compared them with its forecasts/predictions. Tables have been done showing predictions that we would like happen on three years.

On the first table below, we think that the number of exoskeleton hands sold will increase. Few exoskeletons are sold each year per company. Those products are unknown from public and expensive. A lot of people can't buy it. However, with a product like the exoskeleton hand, more affordable to people and with a good quality, the number might increase slowly at the beginning and then faster.

We can do an estimation of 900 exoskeleton hands sold the first year. The budget is for retailers, so the exoskeleton price is to 11 200 DKK. It is assumed that the price will not change during those three years. Variable costs correspond to the cost of purchase.

Here is the table that we expect for the first three years when the product will be on the market.

REALISTIC	N	N+1	N+2
NUMBER OF SALES	900	1 100	1 500
SALES PRICE	11 000	11 000	11 000
TURNOVER	9 900 000	12 100 000	16 500 000
VARIABLE COSTS	3 700	5 200	8 100
	3 330 000	5 720 000	12 150 000
CONTRIBUTION MARGIN I	6 570 000	6 380 000	4 350 000
PROMOTION	300 000	250 000	100 000
CONTRIBUTION MARGIN II	3 030 000	5 470 000	12 050 000

Table 33. Realistic budget.

With a number of 900 exoskeletons hands sold the first year, we have a benefit of 10 080 000 DKK. As the number of sales increases, the profit also increases. The promotion of the product is higher the first year with a budget of 300 000 DKK. It is for launching the product on the market, being known from our customers but also from the public. In the next two years, the budget will decrease due to the promotion done the first year. We can see at the end of the first three years, a turnover increasing because of the number of sales increasing also and a budget for the promotion decreasing progressively.

The two next tables represent a possible percentage of sales increasing or decreasing.

On the optimism table, the number of sales increase, so the turnover. Concerning the variable costs, the company will order the necessary components for 900 exoskeletons. However, they will sell more than expected, they will have to order more materials. The variable costs represent the difference between the 25% of orders more and the realistic budget. We can see so that the contribution margin II is higher than the realistic.

OPTIMISM +25%	N	N+1	N+2
NUMBER OF SALES	1 125	1 375	1 875
SALES PRICE	11 000	11 000	11 000
TURNOVER	12 375 000	15 125 000	20 625 000
VARIABLE COSTS	925	1 300	2 025
	1 040 625	1 787 500	3 796 875
CONTRIBUTION MARGIN I	11 334 375	13 337 500	16 828 125
PROMOTION	300 000	250 000	100 000
CONTRIBUTION MARGIN II	11 034 375	13 087 500	16 728 125

Table 34. Optimism budget.

On this table, the expectation is 25% lower than expected. We can see that the number of sales, the turnover decrease. Concerning the variable costs, there are the same than for the realistic budget. The company will order materials for 900 exoskeleton hands. That’s why, the contribution margin is much lower than in the realistic budget. The company must sell more products if they don’t want to be in deficit.

PESSIMIST -25%	N	N+1	N+2

NUMBER OF SALES	675	825	1 125
SALES PRICE	11 000	11 000	11 000
TURNOVER	7 425 000	9 075 000	12 375 000
VARIABLE COSTS	3 700	5 200	8 100
	2 497 500	4 290 000	9 112 500
CONTRIBUTION MARGIN I	4 927 500	4 785 000	3 262 500
PROMOTION	300 000	250 000	100 000
CONTRIBUTION MARGIN II	4 627 500	4 535 000	3 162 500

Table 35. Pessimist budget.

10.2 Costs

The costs of a company permit to know how much each part of a product costs. When we know the prices of different parts, we can determine the cost incurred in the manufacturing of a product which in turn determines the minimum selling.

Below, the costs of the material, mechanical and electronic parts of the exoskeleton hand are reported.

MECHANICAL PART

PRICE MECHANICS	**62,52 €**
	464,48 DKK

ELECTRONICAL PART

PRICE ELECTRONICS	**312,91 €**
	2324,94 DKK

COST MECHANIC AND ELECTRONIC

TOTAL COST	**375,43 €**

	2789,42 DKK

The total cost for the mechanical and electronic parts is 2 789,42 DKK for one exoskeleton hand.

10.3 Conclusion

With the forecast for the first three years that the product will be made available in the market, we hope that it will be successful and sales will increase during those three years. If this is not the case, a 25% drop in sales will put the company in some difficulties and force it to review its strategy.

11 Future improvements

The product designed in this project can help people by giving them more strength. This is was the goal of this project, and therefore this is a success. Apart from that a product as this exoskeleton hand that works together with the human body can always be improved. The design of this exoskeleton hand for example can be refined. In this team there was no one with experience of designing an ergonomic product. There was also no one with experience of designing a product to be used by people every day. In order to make this product marked ready more effort is necessary on these topics.

Furthermore also the electronical and mechanical parts need more testing and refining in order to make this exoskeleton hand reliable.

A summation of possible future improvements is shown below.

- Redesigning of the hand and arm structure to make it more ergonomically.
- Redesigning of the hand and arm structure in order to make the 3D print process easier.
- Redesigning of the hand and arm structure so it is able to survive the stresses during daily usage.
- Checking, updating and minimizing the electronic and mechanical parts necessary.
- Testing the mechanical structure on strength and durability.
- Testing the system on different daily situations.
- Testing the electronics in order to find errors or possible improvements.
- Designing of a cover to protect the parts from damage.
- Designing a cover for the electronics to fit in the bag. All the cables, plugs and sensors could have an improved isolation.
- Rethink the safety measurements.
- Make a program to automatic update the dimensions of the .stl parts related to the dimensions of the user.
- Make a maintenance plan.
- Work on certifications such as CE, ISO…
- Make a lifecycle analysis and use the result to improve the product.

- Improve the interface system, which includes now only a display, without any iteration. A interactive menu could be programmed, working along with pushbuttons or potentiometer, so the user could interact with the exoskeleton, change its sensitivity, etc.
- There are several possible improvements in sensing aspects: force measurement could be acquired with filtering algorithms, so it would be more precise, or using other type of sensors, like EMG, which were one of our options. This would allow to reduce sensors on the hand, so it would be more comfortable. An important improvement can be done in current sensing. It could have an additional amplification of the signal, but the problem in this project was that with 0A it's 2.5 V, so when introducing amplifiers there were problems when inverting polarity. Another sensor chip could be selected for this function, or finding another way of detecting when the hand is holding an object.

12 Conclusion

The goal of this project was designing an affordable and comfortable device that helps people suffering from loss of strength in their hand so they can fulfil daily tasks. This overall goal was divided in smaller, more measurable goals. This makes it possible to evaluate our design by comparing it to the criteria's we set up before.

In general the exoskeleton hand meets the initial technical criteria, what makes it a success. The force and speed delivered by the actuators meets the demand. And the controls are simplified to make it easy for the user to use the exoskeleton hand. In addition, it is comfortable to wear because of the light weight and compact structure. The battery delivers enough power to supply the energy system for more than 12 hours. And the parts of the frames are created in an eco-friendly material PLA.

Apart from these initial criteria's we also discovered more important factors during the process of the project. One of them is safety, after testing the force delivered by the motor it turned out to be important to work on safety. This because motor is capable of damaging objects or even harm the user or other persons. We considered different options to make the exoskeleton hand safe. But safety needs more research and the design more safety measures to make the device ready for the market.

Another criteria discovered during the process is the adjustability of the design. The dimensions of a human hand are different for every person. This makes it important to have a design that can easily be adjusted to the user. But it also has in impact on the production process. Because of the different dimensions it is very hard to use a moulding process. The solution was using 3D printers for producing the parts of the frame.

Looking at the total final design, the conclusion is that the device is a good proof of concept. In order to make it a final product ready for the market it needs more research a refining.

Regarding the business part of the project, analyses including those of the external and internal environments, the product, price and communication have been made to assess the potential market and benefits that may be derived from the exoskeleton hand concept proposed here.

The external and internal analyses of the environment help us to know more about where the product will be development. We could have only few responses to our questions concerning the market and information provided by the authority, it is difficult to say exactly the potential customers interested by the product. Different steps must be correct to access the Danish market concerning the law. However, the exoskeleton hand doesn't have other competitors on the market and can have its chance to be successful. The product could have a good promotion and the price, 20 000 dkk for customers is an opportunity for them to buy it. The price is not so high and they can permit them to offer it. The revenue in Denmark is higher than in other countries.

With all researches, calculations and analyses done, Danish customers might be interested in our product. In despite, the exoskeleton hand must have some improvements to be sell on the market concerning the quality, the safety of the product, the visual aspect. A deeper analysis, researches on the medical sector, datas on people with a lack of strength, and a survey addressing to those persons should be done.

Overall we conclude that the device needs more research and development in order to make it sellable. Apart from that, there is a market for the hand and the concepts for the exoskeleton hand are proven.

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