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P.E.G.A.S

Powered Exoskeleton Grip Amplifying System

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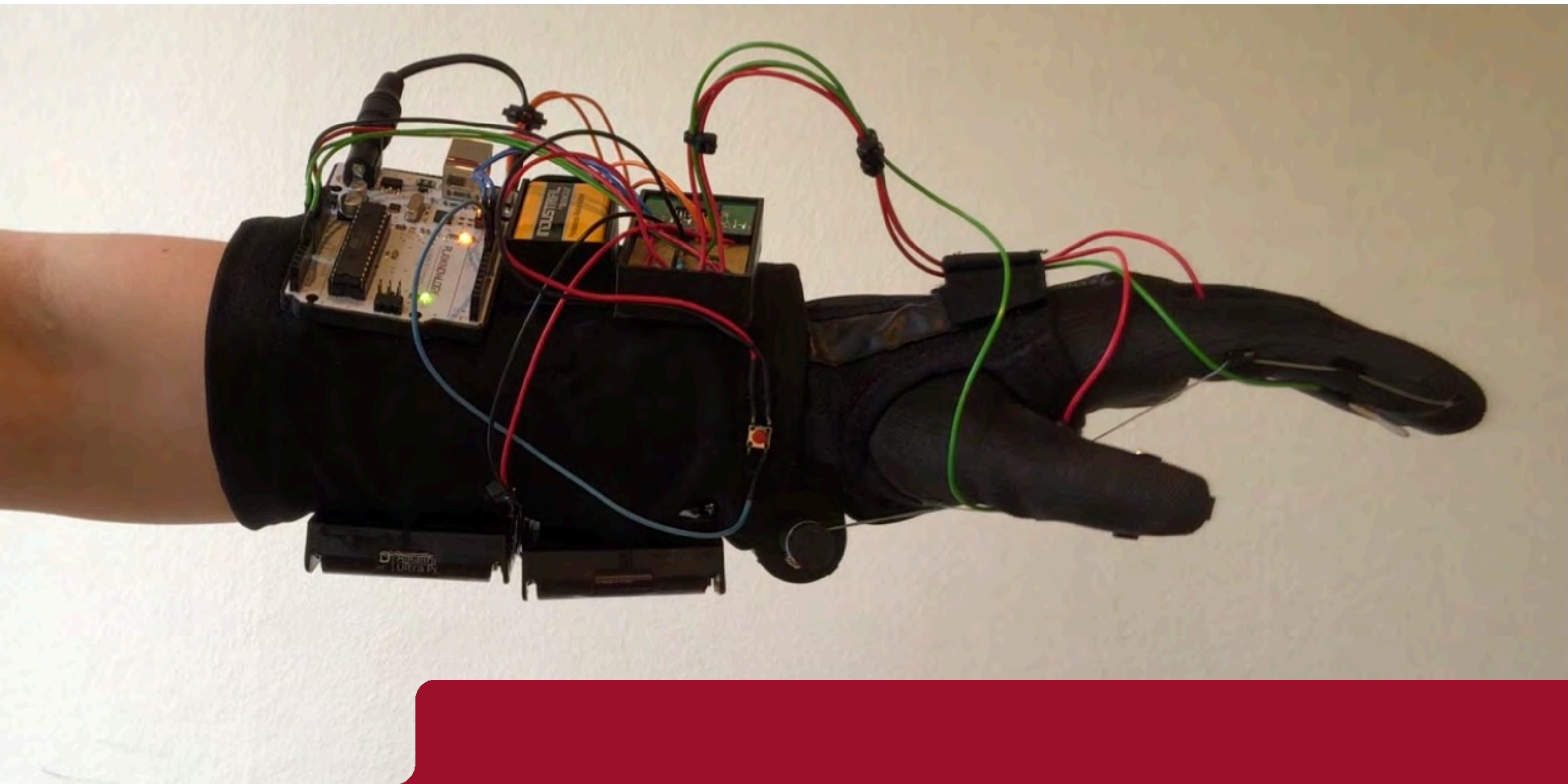

KTH ROYAL INSTITUTE OF TECHNOLOGY
SCHOOL OF INDUSTRIAL ENGINEERING AND MANAGEMENT

P.E.G.A.S

Powered Exoskeleton Grip Amplifying System

MALIN DYBERG, ELVIRA TROILLET

Bachelor's Thesis at ITM
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Abstract

In this bachelor's thesis, the development and construction of a soft exoskeleton for a human hand is described. The purpose of the project includes evaluating what type of exoskeleton that is most suitable for aiding the user in activities of daily living and how this exoskeleton can be constructed in order to increase grip strength in the human hand. In addition, the prototype should be portable and not inflict any harm on the user. The necessary theoretical research is thoroughly conducted followed by the construction of the final prototype. The purpose of the project is achieved, resulting in a flexible, portable and safe exoskeleton which with satisfaction can aid the user in its activities of daily living. However, this prototype is limited to exclusively include the thumb and index finger, and in further work the prototype can be developed to include all five fingers of the human hand.

Keywords: Exoskeleton, mechatronics, Activities of Daily Living, ADL, grip strength, Arduino

Referat

I detta kandidatexamensarbete behandlas utvecklingen och konstruktionen av ett mjukt exoskelett för den mänskliga handen. Syftet med projektet är att undersöka vilken typ av exoskelett som passar bäst för att hjälpa användaren med aktiviteter i det dagliga livet, samt hur detta exoskelett kan konstrueras för att förstärka greppet i handen. Prototypen ska även vara bärbar och inte skada användaren. Den nödvändiga teorin presenteras, följt av konstruktionen av den slutgiltiga prototypen. Syftet med projektet uppfylls och resulterar i ett flexibelt, portabelt och säkert exoskelett som kan hjälpa användaren med aktiviteter i det dagliga livet. Dock är denna prototyp begränsad till att endast inkludera styrning av tummen och pekfingret, och prototypen kan således i framtida arbeten utvecklas till att inkludera samtliga fem fingrar på den mänskliga handen.

Nyckelord: Exoskelett, mekatronik, aktiviteter i det dagliga livet, ADL, greppstyrka, Arduino

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Abbreviations

3D	Three Dimensional
ADL	Activities of Daily Living
DC	Direct Current
DIP	Distal Interphalangeal Joints
FSR	Force Sensing Resistor
IDE	Integrated Development Environment
IP	Interphalangeal Joints
MCP	Metacarpophalangeal Joint
N	Newton
Ncm	Newton Centimeter
PIP	Proximal Interphalangeal Joints
PLA	Polylactic Acid
RPM	Revolutions Per Minute
V	Volt

Chapter 1

Introduction

Being able to fully use the human hand is of great importance for many different reasons, not to mention living a normal and functioning daily life. Unfortunately, many peoples lives are changed for the worse after suffering a disease or accident such as multiple sclerosis, arthritis or stroke [1], leaving them with impaired functions in the hand. This, as well as reduced hand functionality due to ageing, is something that diminish the standard of living amongst too many individuals in our society. This thesis explores the possibility of using a soft exoskeleton for enhancing grip strength in the human hand.

1.1 Background

There are various reasons why a person might have reduced muscle function in their hand. Individuals who have suffered from a stroke or an accident might be in need of assisting grip strength. For these individuals and the elderly, the usage of an exoskeleton for increased grip strength might be useful in order to increase quality of life and aid in Activities of Daily Living (ADL) such as dressing or feeding [2]. This is a problem that could be solved with a mechatronic solution.

A powered exoskeleton is an external mechanical skeleton controlled by an electrical system. Using various technologies, for example electric motors, pneumatics or hydraulics, an external skeleton can be used to increase strength and endurance in different body parts, such as the fingers of a human hand [3].

1.2 Purpose

The aim of the thesis was to construct a prototype of a mechanic exoskeleton that could aid in strengthening the users grip. The construction should be completely portable and with great satisfaction fulfill the requirements of ADL for the user. It should not be too heavy nor harm the user, and it should be easy to use. The following research questions were answered:

- What type of exoskeleton is most suitable for aiding the user in activities of daily living, while still being portable and not harming the user?
- How can this exoskeleton be constructed to increase grip strength in the human hand?

1.3 Scope

This project was limited in regards to time and resources, which is why some limitations had to be set on the construction. The budget for this project was 1000 SEK and the time limited to one term on half speed. Because of the limitations the aspirations of the project were narrowed down to a construction which, without harming the user, could open and close the thumb and index finger of a hand through user interaction.

1.4 Method

Two prototypes, Prototype 1 and Prototype 2, were created in the process of achieving the final prototype. The final prototype included steering and control of the index finger and the thumb with the purpose to enhance grip strength in the human hand. It consisted of a soft glove with force sensing resistors installed on the fingertips in order to sense intention of applying pressure onto an object. On the palmar side of the hand, two fishing lines were installed along the path of the inside of the index finger and the thumb. Along the intended path of the lines plastic tubes were attached. The fishing lines were threaded through the tubes and thus allowing for movement with low friction along the intended path. The lines simulated tendons in the human hand, and were connected to a DC motor via a spool and collet, see figure 1.1. The construction enabled assistance in grip movement, hence assuming that the user would be able to open the hand independently by pressing a button placed below the thumb. An Arduino Uno microcontroller was used to connect the system and control its parts.

Figure 1.1. The dorsal side of the final prototype, picture taken by authors.

Chapter 2

Theory

The following chapter covers the necessary theory behind the decisions and conclusions in this project.

2.1 Exoskeletons

Existing exoskeletons for hand rehabilitation are usually constructed with a design ranging from more rigid to a softer structure. The more rigid exoskeletons are made with a hard and strong frame and are often heavy and controlled by complex algorithms. Generally, each finger is driven by an individual motor which tends to increase price and impair flexibility [4]. With a rigid exoskeleton the user is also at greater risk of suffering from secondary injury which may lead to a deteriorated user experience [5].

The softer exoskeletons are considered more flexible, lightweight and safe compared to the more rigid systems, hence they may be preferable for the user [6]. The disadvantages of a soft system is that they often do not support lateral pinching, cannot prevent hyperextenstion of the joints and often are not as vigorous as the rigid systems [7]. With a soft structure it is also more difficult to achieve greater grip force, however a gripping force of up to 35 N has been suggested to be within the range of sufficient force to fulfill the requirements of ADL [5].

2.2 Activities of Daily Living

Activities of daily living includes the basic everyday tasks that are essential for self-care and general well being, such as bathing, dressing and feeding [2]. The categorization of ADL can be used as a tool for measuring an individuals functional status, securing appropriate care support for the individual or diagnosing them with an impairment. Furthermore, it can be used to relate functional outcomes to specific diseases or stages of chronic diseases [8].

Western University in Canada conducted a study where the required grip force for each finger in 19 different ADL was measured on 25 healthy participants and

21 with hand arthritis. According to this study, a gripping force between 1.4 ± 0.6 N and 34.8 ± 1.6 N is needed for a healthy person to perform ADL [9]. Figure 2.1 shows the required grip force of seven precision grip tasks that are dominated by the thumb and index finger.

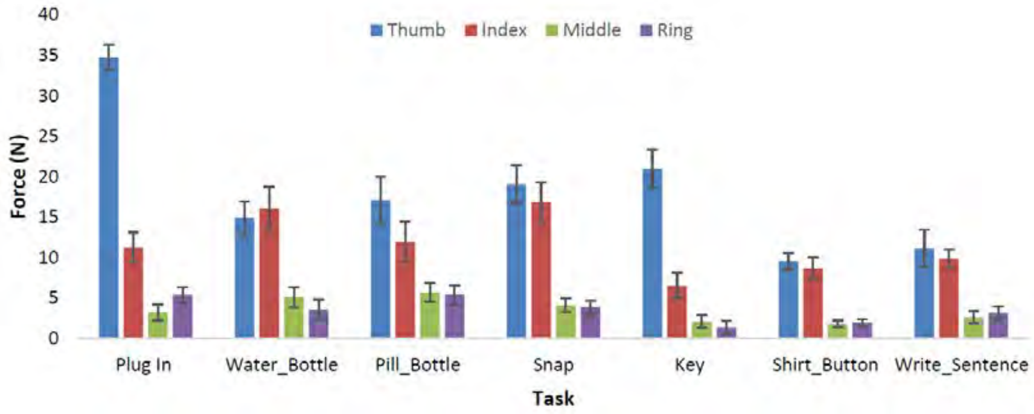

Figure 2.1. Maximum force for each finger of a healthy human in precision grip tasks. These tasks included plugging in a toaster, open bottles, snap a button, turn a key, button a shirt and write a sentence [9].

2.3 Anatomy

The tendons in the fingers allow for flexion and extension of each finger in the human hand via the muscles of the arm. The three major bones, distal phalange, middle phalange and proximal phalange, constitutes the structure of the finger. The joints connecting the bones are the Distal Interphalangeal Joints (DIP), Proximal Interphalangeal Joints (PIP) and Metacarpophalangeal Joints (MCP). However, the thumb consists only of the distal phalange and the proximal phalange, connected by the Interphalangeal Joint (IP) and the Metacarpophalangeal Joints (MCP) [10]. The antanomy of the human hand is illustrated in figure 2.2.

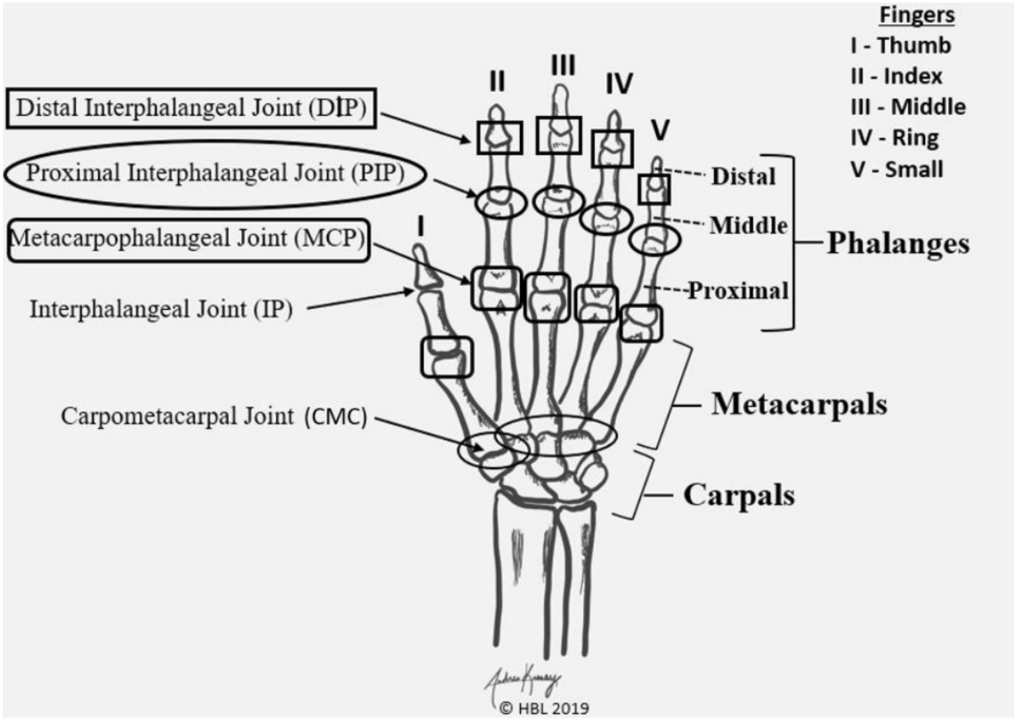

Figure 2.2. Bones and joints of the human hand [9].

2.4 Force Sensing Resistors

Force Sensing Resistors (FSR) can be used for measuring applied force on a specific surface, for example a fingertip. The sensor contains a layer of conductive ink and when pressure is applied on the sensor a specific resistance is generated. This resistance can be measured and converted into a value that can be interpreted in order to determine the pressure. More pressure generates less resistance and vice versa. Most FSR can sense forces ranging from 1 N to 100 N [11].

2.5 Push button

An Arduino push button has four legs of which two are used to either connect or disconnect two points of a circuit depending on whether the button is pushed down or not. Depending on the stage of the button, the output will be either 1 or 0, which can be read by connecting one of the remaining legs to an Arduino pin. The result can then be used in order to control any function in the system that the push button is intended to control, for example the power supply to a motor [12].

2.6 DC Motors

A DC motor is the most simple kind of motor and was therefore chosen for this project. It is simple to use, inexpensive and easy to maintain. However, unlike step motors, the exact rotational angle of the motor cannot be controlled. The DC motor converts electrical energy to mechanical energy by changing the polarity in the motor, causing magnets to turn and generate torque. A DC motor is illustrated in figure 2.3. Furthermore, the motor runs at different fixed speeds depending on applied voltage, and the direction of the rotation can be changed by changing the direction of the electrical current through the motor [13].

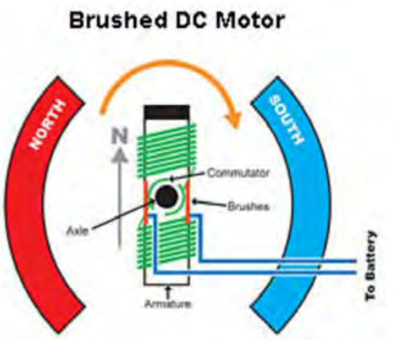

Figure 2.3. Illustration of a DC motor [14].

2.7 H-bridges

H-bridges are used to control the direction of the electric current in motors, enabling the motors to rotate in both directions. An H-bridge is a circuit consisting of four switches in an H-formed formation. The H-bridge is then connected to a power source, ground and the motor to be controlled, see figure 2.4 where *S1* to *S4* denotes the four switches. Depending on the positioning of the switches, the current from the power source will run in different directions through the motor and the motor will therefore rotate clockwise or counterclockwise [15].

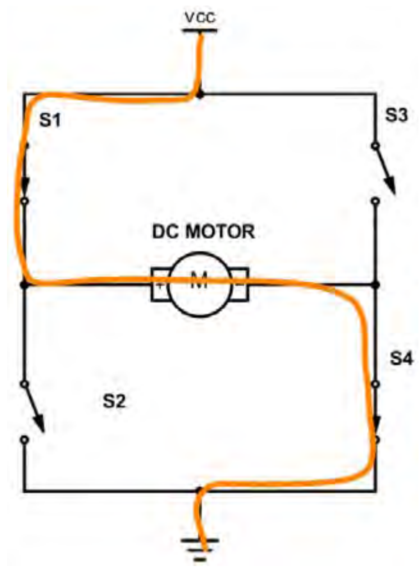

Figure 2.4. Circuit diagram of H-bridge [15].

2.8 Arduino

The Arduino family is an open-source electronics platform of several different microcontrollers. Microcontrollers are different types of small computers that can be programmed to control devices automatically in various ways. The board used in this project is an Arduino Uno, since it is easy to use, easy to access and inexpensive. The Arduino Uno has 14 digital in- and outputs that can be used for connecting several different components together. It receives and processes data from these components, which can then be used to give different outputs to the system depending on how the Arduino is programmed [16].

Chapter 3

Demonstrator

This chapter covers the development of the construction.

3.1 Construction

Two prototypes of the construction proposal were created in order to aid the user in enhancing grip strength. The first prototype, Prototype 1, was developed in order to investigate the possibilities of the construction, which later led to the improved and final prototype, Prototype 2. The final soft exoskeleton system consisted of several components creating a portable glove that completely covers the hand and the forearm of the user. The construction included the following components:

- Force Sensing Resistors
- Fishing lines
- Plastic tubes
- Push button
- Spool
- Collet
- DC Motor
- H-bridge
- Arduino UNO
- External power source
- PU covered nylon glove
- Wrist cover

The components were assembled on the glove and wrist cover creating the soft exoskeleton, where the index finger and thumb were controlled in order to enhance the users grip. The overall construction is presented in figure 3.1, and the following sections will describe the components more in detail. A diagram of how the electrical circuit connects the components to one another is presented in Appendix A.

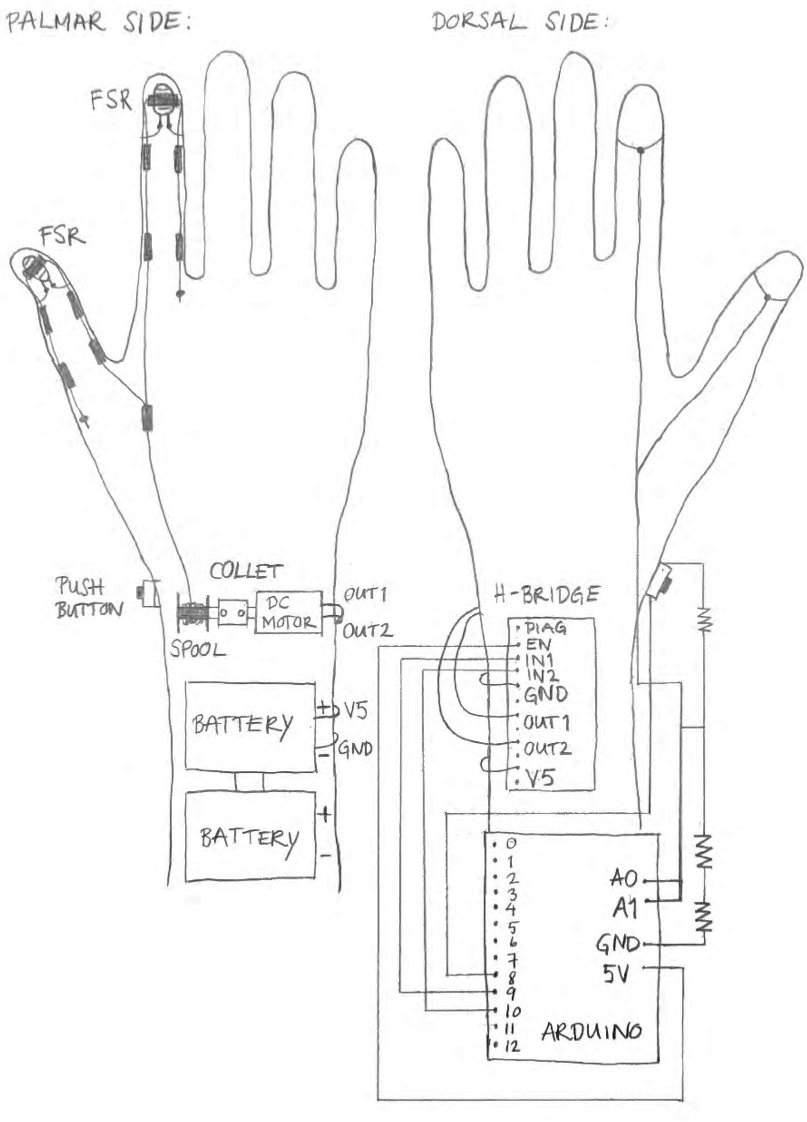

Figure 3.1. Construction proposal, made by authors.

3.2 Force Sensing Resistors

In order to sense the pressure applied between an object and the fingertips of the user, two FSR were placed on each of the fingertips of the index finger and the thumb. The FSR, *FSR 400 short 34-00004*, were chosen for their thin and flexible properties and small size. The resistance had a range of approximately 10 $M\Omega$ at no pressure and 200 Ω at maximum pressure, which corresponded to a detected force between 0,2 N and 20 N. The technical specification and device characteristics provides more details and is found in Appendix B.

3.3 Fishing lines and plastic tubes

The tendons in the fingers were represented by two fishing lines integrated in the soft glove in order to enable flexion motion of the fingers. The two lines ran along the palmar side of the index finger and thumb respectively, threaded through plastic tubes allowing the lines to run with less friction when opening and closing the hand. The plastic tubes were glued onto the glove symmetrically on each side of the phalanges of the two fingers in order to allow for natural bending of the joints. One end of each line were glued onto the glove, while the other ends were connected in a tube on the palm and then gathered on the spool. This spool was then connected to the DC motor via the collet, see figure 3.1.

3.4 Push Button

In order to enable the opening motion of the hand, the push button *ALPS SKHHAQ-A010* was added to the construction. This button was placed below the thumb on the side of the hand, see figure 3.1, allowing the user to easily reach the button with the other hand. As long as the button is pushed down, the motor will rotate in the opposite direction, thus unwinding the fishing line and allowing for the hand to open. The specifications for the push button can be found in Appendix C.

3.5 Spool

A spool was designed in order to gather the excessive fishing line, see figure 3.2. In order to attain a coherent design, the radius of the axis of the spool was chosen to 2 mm to match the dimensions of the motor shaft. The spool was designed in Solid Edge and then 3D printed. Recycable PLA was used to create the 3D printed component.

Figure 3.2. Spool to gather excessive fishing line, picture taken by authors.

3.6 Collet

The collet linking the axis of the motor to the axis of the spool was constructed out of a 20 mm long aluminium cylinder with a diameter of 12 mm. A 4 mm hole was turned throughout the length of the cylinder to fit the two axes. Two M4 screw threads were created by using a milling cutter. This construction was used to transfer the torque from the motor to the spool, see figure 3.3.

Figure 3.3. Collet to transfer torque from motor, picture taken by authors.

3.7 Motor

The glove system was driven by a 12 V DC Motor, *GR 22*, controlled by an H-bridge, *L9997*. The motor had a rated torque of 0.47 Ncm and a rated speed of 5000 rpm, see technical specifications in Appendix D. However, in order to achieve the purpose of strengthening the grip force the motor was required to provide high torque rather than high speed. Therefore, a motor equipped with a planetary gearbox was necessary. The chosen gearbox, *PLG 24*, provided a gear ratio of 199.3, see technical specifications in Appendix E. By using this combination of the DC motor and the gearbox, the torque was increased to 93.7 Ncm while the speed was decreased to 25 rpm. This was calculated with equations 3.1 and 3.2 [17], where u is the gear ratio, n the rotational speed, M the torque and *in* and *out* represents input and output shaft.

$$u = \frac{n_{in}}{n_{out}} \tag{3.1}$$

$$u = \frac{M_{out}}{M_{in}} \tag{3.2}$$

By using equation 3.3 [17], where M denotes torque, F denotes the force in the fishing lines and r represents the radius of the spool, the maximum force that stresses the lines could be calculated. Since the spool has a radius of 2 mm this resulted in a maximum force of 468.5 N. Consequently, each line could be stressed with a maximum force of about 234 N. This met the requirements of the construction with a good margin, even when losses due to friction in the tubes and the fact that the radius will increase as the line is winded on the spool were taken into consideration.

$$M = F * r \tag{3.3}$$

Furthermore, the motor was powered by eight 1.5 V AA batteries which thus supplied the system with 12 V. This solution was chosen over a single 12 V battery since eight smaller batteries made the glove more appropriate for an as effortless and portable user experience as possible.

3.8 Arduino Uno

The Arduino Uno connects and controls all the electric components of the system. The in- and outputs were connected to the the two FSR, the push button and the H-bridge, which in turn connected to the DC motor and its power source, see figure 3.1. The Arduino itself was powered by a 9 V battery, see figure 1.1.

The software Arduino IDE was used to develop a program that controlled the system. Depending on the inputs from the FSR and the button, the motor would run counter clockwise, clockwise or stop running. This was done by defining conditional statements in the code and enabling the pins connected to the motor as HIGH or LOW depending on desired output. As a result, the current was led through the DC motor in different directions which thereby generated a torque in the desired direction. These statements and the code can be reviewed in detail in Appendix F.

Additionally, the safety and security of the user was ensured by creating conditional statements in the code that would deactivate the rotation of the motor if the FSR surpassed a certain upper limit or detected no pressure at all. Moreover, the user can, at any time, reduce the added grip force by pressing the push button. A flowchart of the code is available in Appendix G.

Chapter 4

Results

As a result of research and testing, two prototypes were created; Prototype 1 and Prototype 2. The final prototype, Prototype 2, fulfilled its purpose of aiding in ADL by adding grip force. This resulted in a completely portable and flexible device, weighing only 560 grams. It was equipped with a motor that applied enough torque in order to aid in ADL, while the system was programmed to eliminate the risk of harming the user.

Prototype 1 was created in order to test the construction proposal in figure 3.1, and then adjust the construction by adding required improvements in Prototype 2, resulting in a greater user experience. Mainly two issues arose with the proposed construction for Prototype 1. Primarily, the strength of the DC motor eliminated the possibility of placing the engine directly on the wrist of the glove, as originally intended, since the high torque contributed to the engine not being kept in place. Additionally, the original placement of the plastic tubes impaired flexion motion of the index finger and the thumb since the tubes collided with each other. Prototype 1 is shown in figure 4.1.

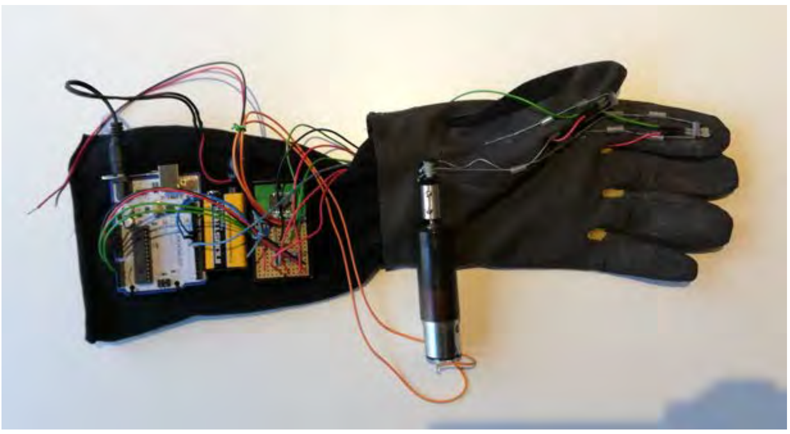

Figure 4.1. Prototype 1, picture taken by authors.

For the second prototype, these issues were addressed by adding the wrist cover that enabled stable placement of the DC motor. The plastic tubes were moved further away from each other in order to provide more space and hence allowing for the flexion motion of the fingers, see figure 4.2. However, the new placement resulted in slightly less enhancement of the grip strength. Since the enhancement still was sufficient to aid in ADL, the placement of the tubes was kept nonetheless.

Figure 4.2. Prototype 2, palmar side, picture taken by authors.

Chapter 5

Discussion

Early in the development process, it became clear that the choice of motor was of crucial importance in order to meet the purpose of constructing a portable exoskeleton that was able to aid in ADL. The motor of choice had to be strong enough to surpass the range of 1.4 ± 0.6 N and 34.8 ± 1.6 N in order to aid in ADL sufficiently. When considering this, the motor *GR 22* with the gearbox *PLG 24* exceeded these requirements excellently. Since the motor considerably exceeds the required force for aiding in ADL, a smaller and less powerful motor could theoretically have been used in order to increase flexibility and mobility. This would also decrease the risk of the construction harming the user due to the motor being too powerful.

The requirements for ADL were also taken into consideration when choosing the FSR for the prototype. The decision of using *FSR 400 short 34-00004* can be questioned as these can only detect forces up to 20 N, which diminish the purpose of a powerful motor since the forces have to be registered in order to be of usage in the construction. The chosen sensors however, were suitable for their flexible properties and size, as larger sensors would not fit on a fingertip. What also needs to be taken into consideration is that in most situations the gripping force will not be concentrated to the small area of the FSR, meaning a sufficient gripping force can be achieved even though the FSR detects a smaller force.

The exact gripping force achieved by the construction was not found, since the readings from the FSR were difficult to interpret and translate into force. Some attempts to calibrate the sensors were made. In summary, it turned out to be highly difficult to obtain accurate readings from the FSR because of their small size and fragile parts. Therefore, finally, no calibration was performed.

To ensure the safety of the user, the code used to control the system was carefully written. It prevented the motor from straining the fishing lines attached to the fingers if either of the sensors detected a too high pressure, but also if the FSR detected a too low pressure. Additionally, at any time the user could press the button, which would lead to the motor unwinding the lines and thus decreasing the pressure, no matter what the readings were from any of the FSR.

Other limiting factors were the budget of 1000 SEK that was provided for this project and the limited time. This led to primarily choosing already existing components in stock at the Department of Mechatronics at KTH Royal Institue of Technology. Consequently, some compromises had to be made when choosing the components.

Chapter 6

Conclusion

The purpose of achieving a construction of a portable exoskeleton that increases grip strength for aiding in ADL was fulfilled. The outcome of this project resulted in two prototypes, Prototype 1 and Prototype 2, and the following research questions were answered:

- What type of exoskeleton is most suitable for aiding the user in activities of daily living, while still being portable and not harming the user?

It was concluded that a soft exoskeleton was most suitable in order to fulfill the requirements of the project. A soft exoskeleton allows for a much lighter construction, enabling complete portability. It is more appropriate for flexible and uncomplicated use, and in favour of its less rigid design it is not as likely to harm the user.

- How can this exoskeleton be constructed to increase grip strength in the human hand?

The construction of the exoskeleton included several components carefully chosen in order to fulfill the requirements. The final electrical components were force sensing resistors, a DC motor with a gearbox, an H-bridge, an external power source and a push button that were connected to one another and controlled by the microcontroller Arduino Uno. The motor and gearbox were chosen specifically due to their high torque properties, and the FSR to be able to detect intended pressure when gripping an object. The components were assembled on a glove and wrist cover, where control of the index finger and thumb were enabled by integrating fishing lines that aided in the flexion motion of the fingers.

The result shows that a soft exoskeleton is suitable for aiding the user in ADL, while simultaneously reducing the risk of secondary injury. The final prototype also successfully fulfilled the goal of being a completely portable device, which facilitates several of the ADL.

Chapter 7

Future Work

There are some areas for improvement in further development of the final prototype. In future work, the system can be made more efficient by including all five fingers of the hand. This will evidently increase stability and enhancement of the human grip strength even further.

In order to increase flexibility and mobility, a smaller and less powerful DC motor could be used. If individual DC motors were integrated for each finger, the user would also be able to control each finger independently. This improvement would more accurately simulate the real features and abilities of the human hand. Furthermore, installing individual motors for each finger would require even less powerful motors, as the motors would only control one finger instead of two fingers as in Prototype 2.

In the current state of the final prototype the user must operate the push button in order to open the hand. This inhibits the possibility of using the exoskeleton on both hands simultaneously and requires the user to be able to fully operate its other hand, which may not always be the case for some individuals. Hence, a possible improvement for the final prototype would be replacing the push button with another mechanism, for example voice control. This would provide the user with the option of independently choosing how to use the other hand.

So far, the exoskeleton will only operate within a specific range of pressure. Since it requires different amounts of pressure to grip different kinds of objects, depending on their fragility and weight, an improvement in further development is to integrate a regulation of the pressure limits. A keypad could be used for allowing the user to choose between different levels of additional pressure applied in the grip. In order to make the exoskeleton even more operational, a hands-free solution such as voice control could be used in this case as well.

The current design leaves several sensitive components completely exposed to the environment. Wear can be avoided by for example protecting the force sensing resistors with a small gel pad that evens out the pressure applied on the component, or protecting the wires attached to the Arduino Uno and DC motor with some kind of protective or water resistant fabric. The latter would allow for the prototype being more useful for several types of ADL, such as bathing, since it would make the prototype more resistant to water. These improvements would minimize the risk of damaging the components and would be preferable in order to enable diligent use of the prototype, thus making it a product more suitable for ordinary use.

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Appendix A

Electrical Circuit

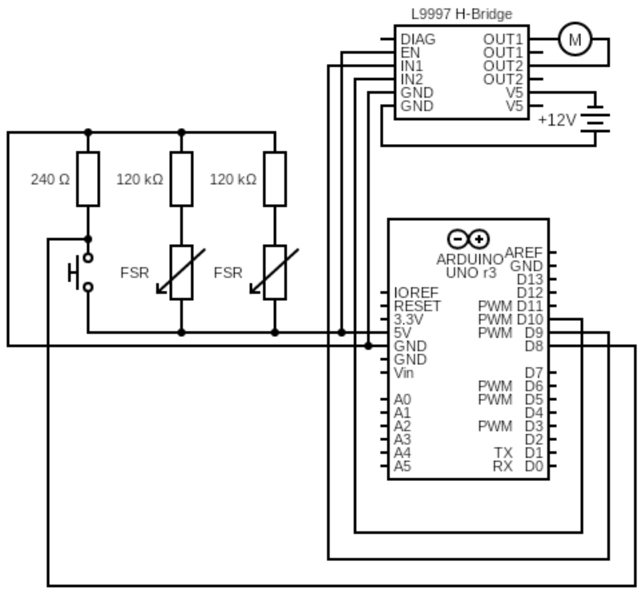
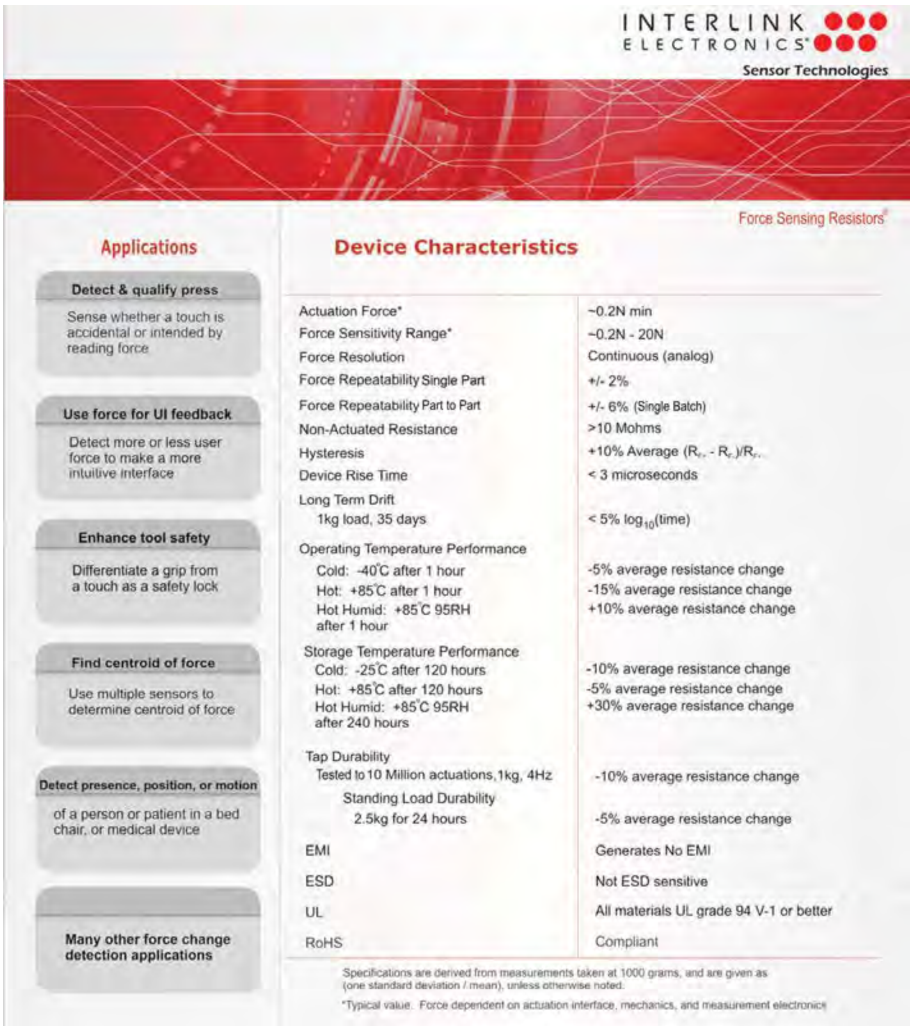


Figure A.1. Circuit diagram of the electrical circuit made in *Circuit Diagram*.

Appendix B

Force Sensing Resistor specification


INTERLINK ELECTRONICS

Sensor Technologies

Force Sensing Resistors®

Applications

Detect & qualify press
Sense whether a touch is accidental or intended by reading force

Use force for UI feedback
Detect more or less user force to make a more intuitive interface

Enhance tool safety
Differentiate a grip from a touch as a safety lock

Find centroid of force
Use multiple sensors to determine centroid of force

Detect presence, position, or motion
of a person or patient in a bed chair, or medical device

Many other force change detection applications

Device Characteristics

Actuation Force*	~0.2N min
Force Sensitivity Range*	~0.2N - 20N
Force Resolution	Continuous (analog)
Force Repeatability Single Part	+/- 2%
Force Repeatability Part to Part	+/- 6% (Single Batch)
Non-Actuated Resistance	>10 Mohms
Hysteresis	+10% Average $(R_{F+} - R_{F-})/R_{F+}$
Device Rise Time	< 3 microseconds
Long Term Drift 1kg load, 35 days	< 5% $\log_{10}$(time)
Operating Temperature Performance	
Cold: -40°C after 1 hour	-5% average resistance change
Hot: +85°C after 1 hour	-15% average resistance change
Hot Humid: +85°C 95RH after 1 hour	+10% average resistance change
Storage Temperature Performance	
Cold: -25°C after 120 hours	-10% average resistance change
Hot: +85°C after 120 hours	-5% average resistance change
Hot Humid: +85°C 95RH after 240 hours	+30% average resistance change
Tap Durability Tested to 10 Million actuations, 1kg, 4Hz	-10% average resistance change
Standing Load Durability 2.5kg for 24 hours	-5% average resistance change
EMI	Generates No EMI
ESD	Not ESD sensitive
UL	All materials UL grade 94 V-1 or better
RoHS	Compliant

Specifications are derived from measurements taken at 1000 grams, and are given as (one standard deviation / mean), unless otherwise noted.

*Typical value. Force dependent on actuation interface, mechanics, and measurement electronics

Figure B.1. Technical specification and device characteristics for the force sensing resistor.

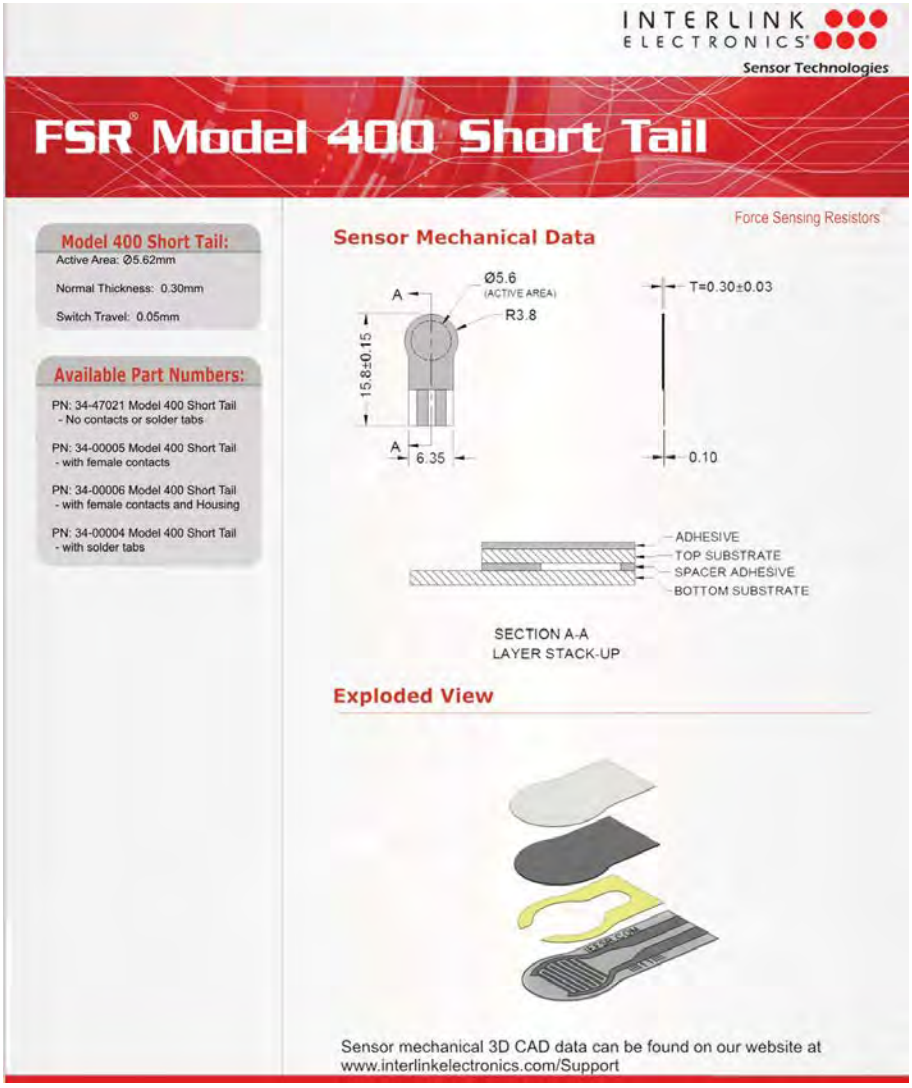


Figure B.2. Technical specification and exploded view of the force sensing resistor.

Appendix C

Push button specifications

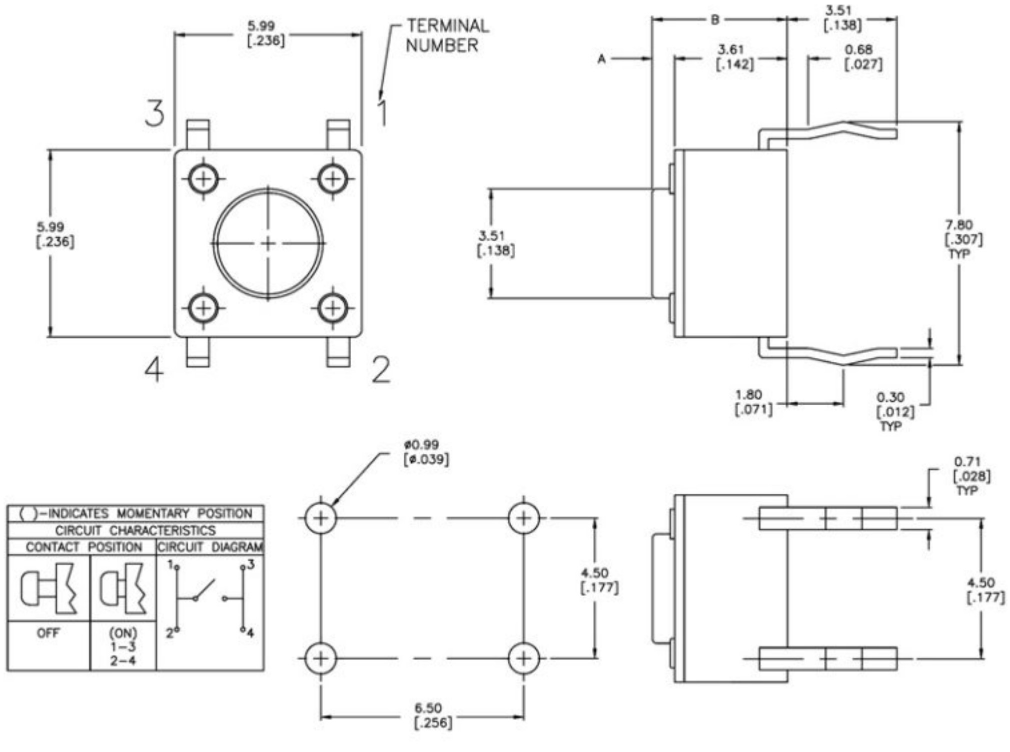


Figure C.1. Specifications for the push button *ALPS SKHHAQA010*.

Appendix D

Motor specifications

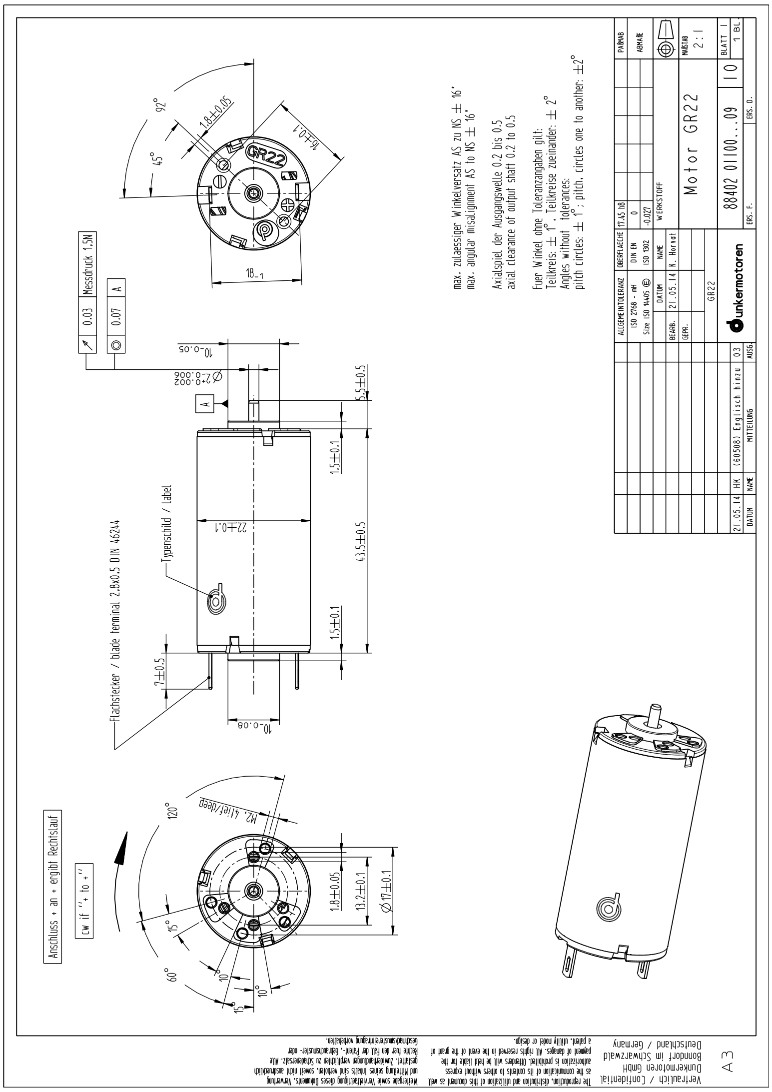


Figure D.1. Dimensions of the DC motor *GR 22*.

Typ GR 22

Duty cycle	:		S1		
Insulation Class	:		E EN 62114 (120°C)		
RFI compatibility	:		-		
Test method	:		VDE 0530 : EN 60034		
Rated Voltage	U_N		12		V
Rated Current 2)	I_N	≤	0,47		A
Rated Input Power 2)	P_{1N}	≤	5,64		W
No load current 1)	I_0	≤	0,14		A
Rated torque 2)	M_N		0,47		10^{-2}Nm
Rated speed 2)	n_N		5000	±10%	min^{-1}
Rated power 2)	P_{2N}		2,46		W
Friction torque 1)	M_R		0,1		10^{-2}Nm
Rated efficiency 2)	η_N		43,5		%
Maximum torque 1)	M_{max}		-	±10%	10^{-2}Nm
Stall torque 1)	M_A		1,4	±10%	10^{-2}Nm
No load speed 1)	n_0		8700	±10%	min^{-1}
Damping constant 1)	K_D		0,15 0,16		10^{-4}Nmsrad^{-1} 10^{-2}Nm/1000min^{-1}
Rotor inertia	J_R		2,4		10^{-7}kgm^2
Mechanical time constant 1)	τ_m		15,6		10^{-3}s
Start current 1)	I_A		1,14	±10%	A
Demagnetisation current 1)	I_{Fm}	≥	-		A
Armature/Rotor resistance 1)	R_R		6,66	±10%	Ω
Winding resistance 1)	R_A		10,53	±10%	Ω
Torque constant 1)	K_M		1,3		10^{-2}NmA^{-1}
Winding inductance 1)	L		5,3		10^{-3}H
Electrical time constant 1)	τ_e		0,5		10^{-3}s
Start voltage 1)	U_A		1,8		V
Maximum output power 1)	P_{2max}		3,2		W
Maximum speed 2)	n_{max}		10000		min^{-1}
Maximum body temperature 2)	ϑ_G		75		°C
Thermal resistance 2) Winding to motor body Motor body to ambient	 R_{th1} R_{th2}		 11,32 16,98		 KW^{-1} KW^{-1}
Weight	---		0,05		kg

1) $\vartheta_W = \vartheta_R \cong$ 20 °C -
2) $\Delta\vartheta_W = \Delta\vartheta_{W zul.}$ = 100 K -

A4

DATUM	NAME	MITTEILUNG	AUSG.
12.07.2007	SD	Leerlaufstrom geändert	03

	DATUM	NAME
BEARB.	27.01.1983	Prinz
GEPR.	27.01.1983	Pfendler
ERSTVERW.		

PAßMAß
ABMAßE
MAßSTAB

5.102.014

GR 22

Alcatel·Lucent dunkermotoren

40201012 48

BLATT 2 BL.

ERS. F. ERS. D.

Figure D.2. Technical specifications for the DC motor *GR 22*.

Appendix E

Gearbox specification

dunkermotoren
advanced motion solutions

PLG 24

Planetary Gearbox PLG 24
Planetengetriebe PLG 24

- High efficiency
- Ring gear and planetary gears made of specific, high grade material
- Planetary carriers and sun wheels made of steel
- Output shaft with dual sleeve bearings
- All stages have straight toothing

- Hoher Wirkungsgrad
- Hohlrad und Planetenräder aus speziellem, hochwertigem Werkstoff
- Planetenträger und Sonnenritzel aus Stahl
- Ausgangswelle doppelt gleitgelagert
- Alle Getriebestufen geradverzahnt ausgeführt

Data
Leistungsdaten

PLG 24												
Reduction ratio/ Untersetzungsverhältnis		4.33	6	18.75	33.2	46	81.2	112.6	143.8	199.3	276	352.6
Efficiency/ Wirkungsgrad		0.9		0.81			0.73					
Number of stages/ Stufenzahl		1		2			3					
Continuous torque/ Dauerdrehmoment	Ncm	30		45			60					
Weight of gearbox/ Getriebegewicht	kg	0.019		0.025			0.035					
Axial load/radial load/ Axiallast/Radiallast	N	5/ 12		5/ 12			5/ 12					

Figure E.1. Technical specification and performance data of the gearbox *PLG 24*.

dunkermotoren
advanced motion solutions

PLG 24

Length motor gearbox combination
Länge Motor-Getriebe-Kombination

Lengths L motor gearbox combination / Länge L Antrieb (mm ± 2)			
	PLG 24		
Stages / Stufenzahl	1	2	3
GR 22	68	75	83

Dimensions
Maßzeichnung

Dimensions in mm / Maßzeichnung in mm

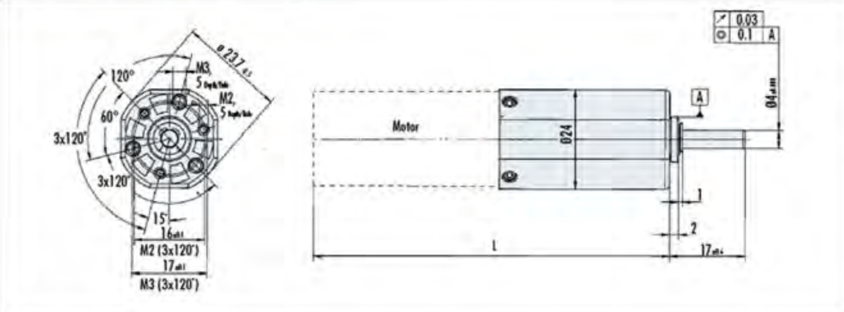


Figure E.2. Technical specification and dimensions of the gearbox *PLG 24*.

Appendix F

Arduino IDE code

```
/*
 *   Code for control of exoskeleton hand
 *   Bachelor's Thesis at ITM
 *   Malin Dyberg and Elvira Troillet
 *   21-04-21
*/

int button = 8;       // Button
bool buttonState = 0; // State of button
int in1 = 9;          // Motor
int in2 = 10;         // Motor
int fsrIndex = A0;    // Force sensor resistor index finger
int fsrThumb = A1;    // Force sensor resistor thumb
int fsrReadingIndex;  // The current reading from the FSR on index finger
int fsrReadingThumb;  // The current reading from the FSR on thumb
int state1 = HIGH;    // state1 and state2 to control spinning direction
int state2 = HIGH;    // of motor
bool handState = 0;   // 0 for open hand, 1 for closed hand


void setup() {
  Serial.begin(9600);
  pinMode(button, INPUT);
  pinMode(fsrIndex, INPUT);
  pinMode(fsrThumb, INPUT);
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
}
```

```
void loop() {

  // Read the FSR pins and store the output as fsr-readings:
  fsrReadingIndex = analogRead(fsrIndex);
  fsrReadingThumb = analogRead(fsrThumb);

  // Read the button-pin and store the output as buttonState:
  buttonState = digitalRead(button);

  // If both of the two sensors get a reading less than 500 the motor
  // will not turn
  if (fsrReadingIndex < 500 && fsrReadingThumb < 500) {
    state1 = HIGH;
    state2 = HIGH;
  }

  // If the hand is open and the input from any of the sensors goes
  // above 500, the motor begins to turn
  if (handState == 0 && (fsrReadingIndex > 500 || fsrReadingThumb > 500)) {
    state1 = HIGH;
    state2 = LOW;
  }

  // If the input for any of the sensors goes above 800, the motor
  // stops rotating and the hand is set to "closed".
  if (fsrReadingIndex > 800 || fsrReadingThumb > 800) {
    handState = 1;
    state1 = HIGH;
    state2 = HIGH;
  }

  // If the input from both sensors goes down to less than 20 again
  // the hand is set to "open"
  if (fsrReadingIndex < 20 && fsrReadingThumb < 20) {
    handState = 0;
  }

  // When the button is pushed the motor will unwind the fishing line
  // so the hand opens up again until the button is unpushed.
  while (buttonState == 1) {
    // Read the button-pin and store the output as buttonState:
    buttonState = digitalRead(button);

    state1 = LOW;
```

```
    state2 = HIGH;

    // State of hand is set to "open"
    handState = 0;

    // Motor will turn in different directions depending on the states
    digitalWrite(in1, state1);
    digitalWrite(in2, state2);
  }

  // Motor will turn in different directions depending on the states
  digitalWrite(in1, state1);
  digitalWrite(in2, state2);
}
```

Appendix G

Flowchart of Arduino IDE code

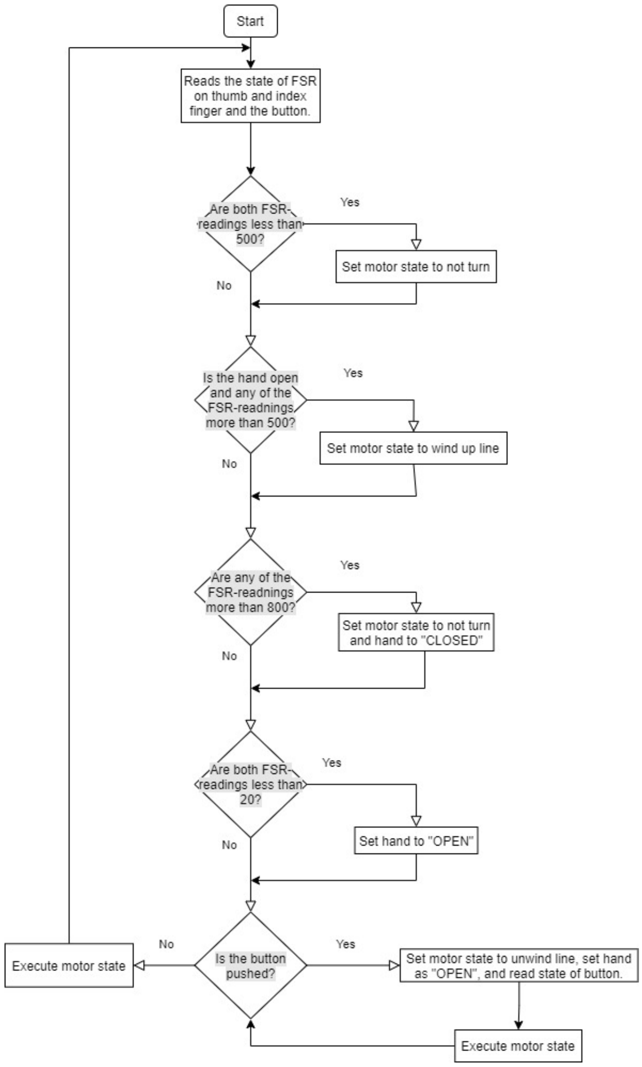


Figure G.1. Flowchart of the Arduino code that controls the exoskeleton, made with *diagrams.net*.

TRITA ITM-EX 2021:45