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Exo-Controlled Biomimetic Robotic Hand

A design solution for control of a robotic hand with an exoskeleton

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Exo-Controlled Biomimetic Robotic Hand

Bachelor's thesis in mechatronics

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Bachelor’s Thesis at ITM
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Abstract

Robotic arms and hands come in all shapes and sizes, they can be general purpose or task-specific. They can be pre-programed by a computer or controlled by a human operator. There is a certain subsection of robotic hands which try to mimic the shape, movement and function of the human hand, these are sometimes known as biomimetic robotics. This project explores the human-robot interaction by creating an anthropomorphic robotic hand with an accompanying exoskeleton. The hand, which consists of a 3D-printed body and fingers, is connected to a forearm where the servos that control the fingers are housed. The exoskeleton connects to the operator's hand allowing finger tracking through a set of potentiometers. This setup allows the operator to intuitively control a robotic hand with a certain degree of precision.

We set out to answer research questions in regard to the form and function of a biomimetic hand and the exoskeleton. Along the way, a multitude of problems were encountered such as budgetary issues resulting in only half the fingers having movement. Despite this, good results were gathered from the functioning fingers and our research questions were answered.

Keywords: Mechatronics, Biomechanical hand, Robotic hand, Exoskeleton, Arduino Servo motor, Potentiometer.

Referat

Robotarmar och händer finns många former och storlekar, de kan vara för allmänna ändamål eller uppgiftsspecifika. De kan programmeras av en dator eller styras av en mänsklig operatör. Det finns en viss typ av robothänder som försöker efterlikna formen, rörelsen och funktionen hos den mänskliga handen, och brukar kallas biomimetisk robotik. Detta projekt utforskar interaktionen mellan människa och robot genom att skapa en antropomorf robothand med tillhörande exoskelett. Handen, som består av en 3D-printad kropp och fingrar, är ansluten till en underarm där servormotorerna som styr fingrarna sitter. Exoskelettet ansluts till operatörens hand vilket möjliggör spårning av fingrarnas rörelse genom ett antal potentiometrar. Detta tillåter operatören att intuitivt styra en robothand med en viss grad av precision.

Vi valde att besvara ett antal forskningsfrågor med avseende på form och funktion av en biomimetisk hand och exoskelettet. Under projektets gång påträffades en mängd problem såsom budgetproblem som resulterade i att bara hälften av fingrarna kan kontrolleras. Trots detta fick vi bra resultat från de fungerande fingrarna och våra forskningsfrågor kunde besvaras

Nyckelord: Mekatronik, Servomotor, Mekanisk hand, Robothand, Arduino, Potentiometer, Exoskelett

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Simon Stenberg and Philip Linder-Aronson
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I/O - Input/Output
IDE - Integrated development environment
Rpm - Revolutions per minute
PWM - Pulse width modulation
USB - Universal serial bus
V - volts

1 Introduction

1.1 Background

The hand and its wrist is one of the body's most complex systems, whilst being one of our most important tools in everyday life. The movement and flexibility of the human hand are essential for common tasks in any person's life. In many fields of today's industry the need for robot arm based manufacturing and management of goods has increased the last decades (Atkinson, 2019). Where in many cases these robotic arms are preprogrammed to do very specific and predetermined repetitive tasks. This often works exceptionally well in production lines of large quantities of products. However, in some instances a more flexible solution can be required (Design Robotics, 2018). A solution where programming a robot arm for a unique task would be too cost inefficient, and a system that can be directly controlled by a human, who's already familiar with the task, would be preferred. In this case a robotic arm which could be directly controlled by the users own movements, would be very useful for performing unique and varying tasks without having to introduce any extra code in the system. Most robotic arms are rarely fitted with hand-like contraptions, and more often than not, instead have some sort of clamp for holding, for example a welding tool. In order to make the robotic-human interaction easier, a mechanical hand could be used in conjunction with the robotic hand in order to efficiently handle something that is suited to be handled by a human but for some reason can't be without risk to the person, for example because of a risk of toxicity or radiation.

This thesis explores a biomimetic robotic hand's interplay with the human body, and also investigates an efficient and simple design which would allow the mechanical hand to move and function similar to the human counterpart.

1.2 Purpose

The purpose of this thesis is to investigate and realize a design of a functional mechanical hand, which will be controlled by the motions of the user's hand. The thesis focuses on answering the following questions:

- *How should a mechanical hand and associated fingers be constructed in order to achieve the mobility and ability to perform basic tasks similar to its biological counterpart?*

- *How will the motions of the user's hand transmit to the robotic hand?*

- *How well does the design mirror the position of the user's finger?*

1.3 Scope

Due to this bachelor's thesis extending over one semester, with both limited time and resources, the complexity of this project will be outlined accordingly. Some form of exoskeleton that can transmit the users motions to the robotic hand will have to be constructed. Functionality will be prioritised over aesthetics and the mobility of the mechanical hand should resemble the mobility of a biological hand, however, not be identical. Since the hand and wrist is extremely complex with a lot of joints and tendons, shortcuts and simplifications will be made in order for the project to fit the time scale and the budget. The hand with its thumb and fingers will be constructed first, and a foundation for the wrist will be added for potential future work.

1.4 Method

In order to gain knowledge and understanding of mechatronic arms, previous research and reports were studied. This enabled us to set realistic expectations for our project and gather valuable insight into pitfalls and solutions from similar projects. Furthermore, medical literature was read to gain an elementary understanding of the anatomy and function of the human hand.

Thereafter, a first prototype was designed in Solid Edge. The components consisted of the motion tracking glove and a rudimentary hand, fingers and forearm; allowing placement of servos. The prototype was created and evaluated with respect to its overall usability and function. Problems in the design of the prototype were investigated and solutions integrated in the next prototype generation. This cycle continued until the finished design.

2 Theory

2.1 The human hand

The human hand is one of, if not the most, mechanically complex part of the human body. The complexity which lies within the hand gives primates, particularly humans, extraordinary dexterity and precision, enabling us to finely manipulate objects. Billions of dollars have been spent over the last century, trying to recreate the mechanical function of a human hand, with limited success.

The hand is made up of 27 different bones which can be seen in figure 2.1 (ElKoura, G. and Singh, K., 2021). At the bottom of the hand there are the eight carpal bones. These bones make up the structure of the wrist and allow for its abduction, extension and flexion movements. The metacarpal bones connect with the carpal bones and are the framework for the palm. With the exception of the first metacarpal, the one connected to the thumb, the metacarpal bones contribute very little to the range of motion. However, the first metacarpal allows for a high degree of movement in our thumb. The opposable thumb has been seen as one of the humans most vital developments, enabling us to finely grasp and manipulate tools and objects. Each finger consists of the bones called the phalanges, these bones pivot to allow for a high degree of movement (A Moran, C., pp.1007-1013).

Our hand movement and strength comes primarily from muscles in the forearm, which are connected to the hand and fingers via tendons. The muscles are located in the forearm due to packaging constraints in the hand, which would impede movement and dexterity. The muscles pull on the tendons which in turn pull on the fingers.

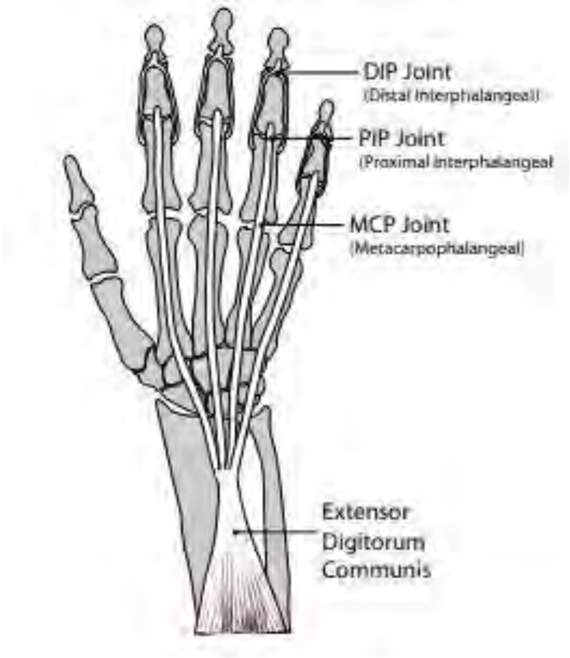

Figure 2.1: The skeletal structure of the human hand

2.2 Potentiometer

A potentiometer is an electro-mechanical transducer, capable of varying resistance via mechanical actuation. This actuation is commonly in the form of a rotary knob, but linear types are also used. The potentiometer has three wires: a power, ground and variable resistance output (Filippi, 2007). By turning the knob, or sliding a slider, the voltage varies from 0 V to V_{max}, where V_{max} is the power fed to the potentiometer (Electrical4U. 2021). As the potentiometer has a maximum range of motion, it is possible to deduce its position based on the output voltage. In the case of a 180° rotary potentiometer, 0 V corresponds to 0°, 0.5 V_{max} to 90° and V_{max} to 180.

2.3 Servo Motor

Servo motors combine a high RPM electric motor with a reduction gear set and a servo amplifier. The servo motor is a closed loop system, with the servo drive acting as an encoder, taking feedback from an internal potentiometer to derive positional and speed feedback (Farnell.com, 2018). The self-contained device can provide highly accurate positional, velocity and torque control of the output shaft. Though the servo is a closed loop mechanism, it is an open loop system in respect to the microcontroller and overall system. This leads to the inability to monitor and correct any potential errors in the position of the shaft.

Although some servo motors offer continuous rotation, the vast majority have an operating angle of 180°, most often split between -90° and 90°. The servo consists of three wires: ground, power and control. The control wire is fed a pulse width modulated signal which corresponds to a certain shaft angle. As seen in figure 2.2, a shorter pulse width corresponds with a lower angle. By feeding the servo with varying length pulses we are able to change the position. A new pulse is sent every 20 ms and by varying how quickly the pulse length changes, we are able to control the speed of the shaft. By sending a constant pulse, we are able to hold the shaft in the same spot whilst maintaining a torque output, resisting any change applied on the shaft (Högsteldt & Söderman, 2016).

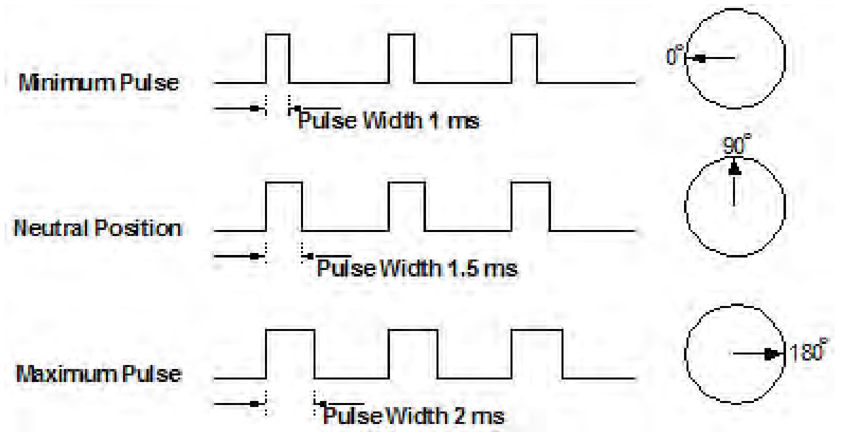

Figure 2.2: The signal from a Pulse Width Modulated source (Projects, E., 2020)

2.4 Arduino Uno

A microcontroller is a small, low power computer dedicated to running a specific program, in contrast with a personal computer which can run several, processor intensive tasks simultaneously, as well as store large amounts of non-volatile data (Design Robotics, 2018). Generally, microcontrollers have read only memory, random access memory, a cheap processor and a selection of I/O ports which handle both inputs and outputs (Brain, 2000).

Arduino is an open source hardware and software platform aimed at consumers and non-commercial applications. The board is based on the ATmega2560 microcontroller and is able to compute several inputs and outputs simultaneously. It has 14 digital input/output pins, 6 analog, a USB port and a power port (Arduino.cc, 2019). The board is programmed via Arduinos C based program called Arduino IDE (Integrated Development Environment).

3 Demonstrator

3.1 Hand and forearm design

The robotic hand being the output part in this setup, is put together with a multitude of 3D-printed parts and servo motors. These are in turn connected with each other and stimulate the movement throughout the fingers by a set of strings running from the servo motors through the finger joints.

3.1.1 Forearm

Our design process for the hand and forearm started with the forearm. The servos were chosen to be located in the forearm as they are bulky and require a large amount of space, relative to the size of the hand (Figure 3.1). The servos will mimic the muscles in the forearm, which extend and contract, pulling the tendons and in turn controlling the fingers. The servos are able to rotate 180°, this motion was used to pull a cable around the servo, which effectively lengthens and shortens the cable on command. Every active finger is connected to two separate servos (except for the thumb which is controlled by just one servo) to enable separate control of the fingers in the hand. Furthermore, we would have two servos to control the wrist movement in a similar fashion. As seen in figure 3.1 there is a central frame housing the servo motors. This frame will act as an attachment point for the Arduino, wrist and consequently, the hand, as well as future outer forearm covers.

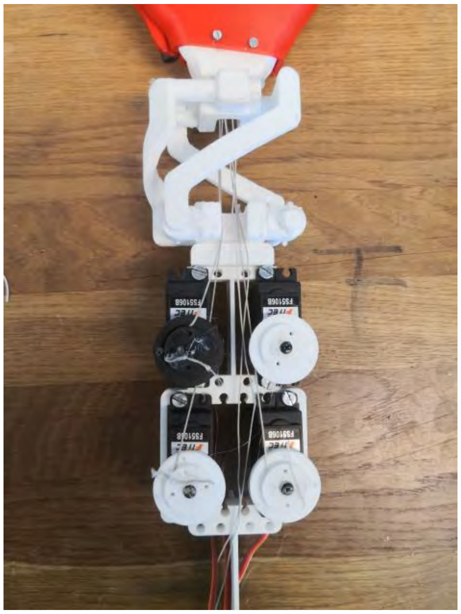

Figure 3.1: Forearm and servo (taken by authors)

3.1.2 Fingers

After the forearm was completed, work started on the fingers. The fingers are one of the most important parts of the project, they are the main moving parts of the robot and account for the majority of the function. As outlined in the theory, the design of the human hand is complex and the result of millions, if not billions, of years of evolution. Therefore, appropriate approximations of the movement, function and dexterity have to be made in our design. Like the human hand, our fingers are made up of 3 separate phalanges connected with a hinge joint.

Getting the correct range of motion with a rigid body, such as the PLA plastic used, is a challenge. Whilst our own flesh can extend and compress, the plastic parts tend to interfere, nonetheless, we were able to produce a finger design where each joint can move approximately 90° from its open position. As seen in figure 3.3, this movement satisfies our requirements on range of motion. To connect the finger to the servos, and get the correct motion, holes are added to the finger to enable the cable to connect and pass through the finger. By rotating the servos 0 - 90 ° from center the finger will contract, by rotating the servos 0 - -90° from center the finger will extend.

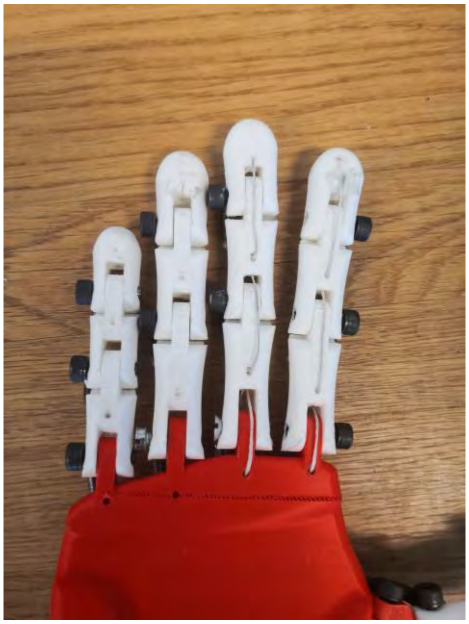

Figure 3.2: Hand and finger construction (taken by authors)

With regard to controlling the finger with a servo there are two schools of thought; either use the full 180° range of the servo for the contraction and use springs for the return motion; or split up the servo in two 90° intervals as this project has chosen to do. Both techniques have their pros and cons, with the former having more power and better accuracy on the contraction, whilst the latter has better control of the extension and is less prone to failure from the spring.

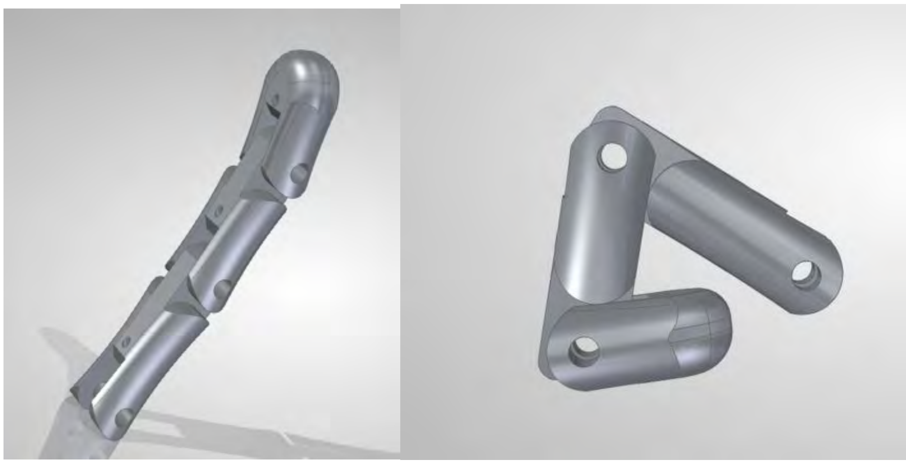

Figure 3.3: Finger in its extended and contracted position (taken in solid edge)

3.1.3 Thumb

Originally the thumb was planned to have a large degree of motion like its real counterpart. However, the budget and time quickly ran out whilst undertaking this project. This led to a forced simplification of the thumb's mechanics as it was decided to focus the effort and funds on other aspects of the hand. The resulting thumb could be compared with a scaled down finger, but with a large base which was angled differently than the rest of the fingers (Figure 3.4). This simulated the motion required for grabbing something, which gave the whole hand some basic "hand-like" functions.

Figure 3.4: Thumb in its open and closed position (taken by authors)

3.1.4 Palm

The palm consists of two pieces of 3D printed PLA with a hollow core. The two parts of the hand are split between the palm and the back of the hand. This enables the cables to run from the fingers, through the palm, to the servo motors. The design of the palm is based on the human hand to best try to mimic its appearance. The top of the palm has flanges where the knuckles would be located on a human hand. These flanges have holes which interface with the fingers allowing for a hinge connection. With regard to the opening and closing of the hand, our mechanical counterpart has a range of motion satisfactory for our demonstrator (Figure 3.5).

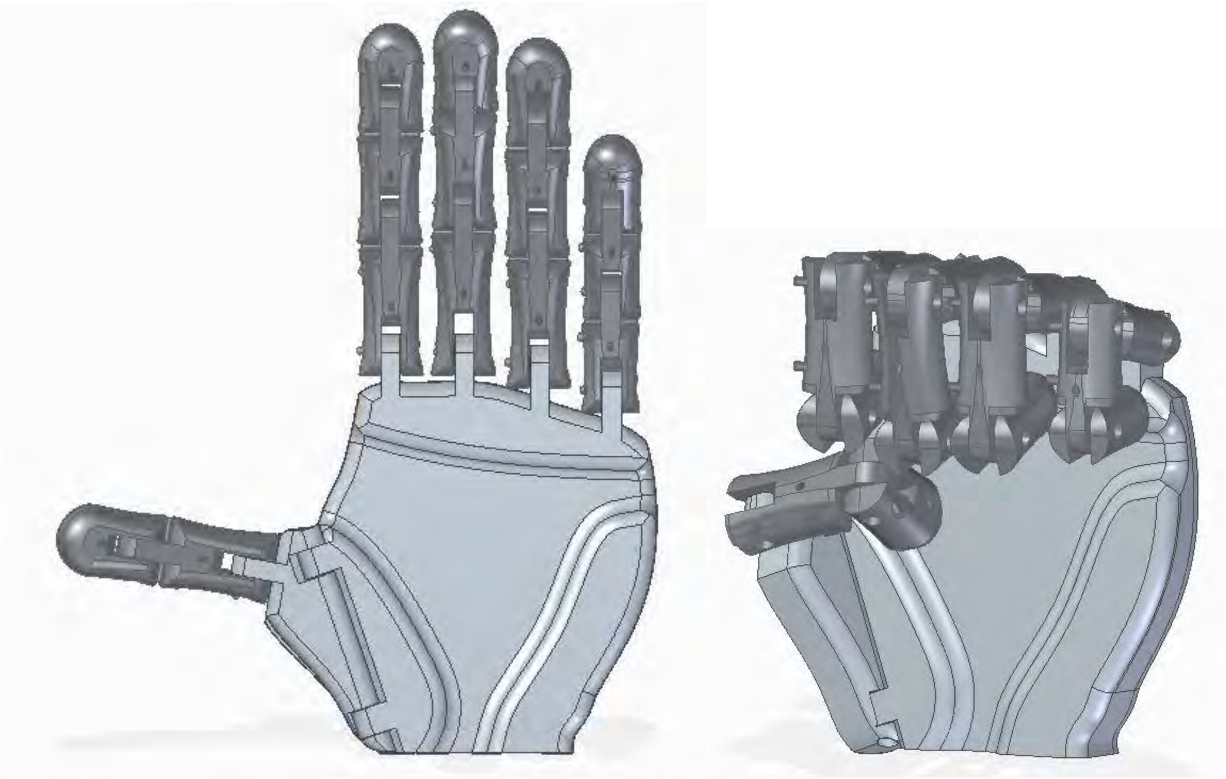

Figure 3.5: The hand in its open and closed position (taken in solid edge)

3.1.5 Wrist

In order to make a mechanical construction that would simulate the wrist's large range of movement, a construction inspired by Will Cogley's explanation (Cogley, 2020) of the wrist design of DLR's super robust robot hand (Guizzo, 2011), was designed and constructed (Figure 3.6). This wrist design consists of two main bodies interconnected by three arms sitting on rotating axles that each allow for a movement in 2 axises. This design allows for a wrist like construction with realistic movement. It allows for more than 90 degrees of translation in any direction starting from a straight position. The main bodies were fitted with an opening in which the lines connecting the fingers to the servo motors would go through the wrist was then connected to the forearm and the robotic hand.

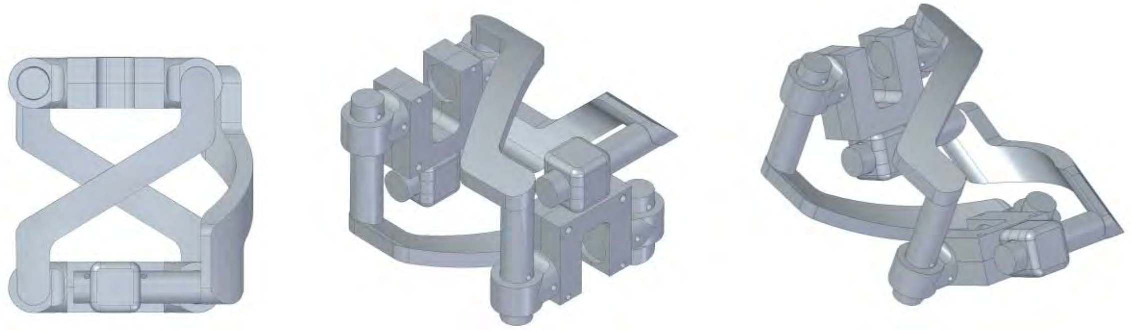

Figure 3.6: The wrist in its neutral, and bent position (taken in solid edge)

3.2 Exoskeleton

The goal of the exoskeleton is for it to be easy to fit on the user's hand and be able to translate the motions and rotations of different parts of the fingers and hand. Motions like the curling of individual fingers or rotation of the wrist, can be registered and sent to the robotic hand (Figure 3.7).

Figure 3.7: Model of the exoskeleton (taken in solid edge)

3.2.1 Finger

To register the motions in the fingers, a mechanical solution was designed that allowed for the outer part of the fingers to move and register motions independently and without interfering with the inner part of the finger, and vice versa (Figure. 3.8). To facilitate this, joints were placed in the shared axis. This gave the system more exact and realistic motions, as well as increased the user's control over the mechanical hand. The two finger parts of the exoskeleton are fitted with lever-like extensions that are connected to the potentiometers. The resulting rotational movements of the fingers are converted to a horizontal movement that moves the potentiometers. The small holes in the bottom of the parts are added in order to accommodate for the varying sizes in human fingers, and gave the option to move the point of attachment to the users own fingers.

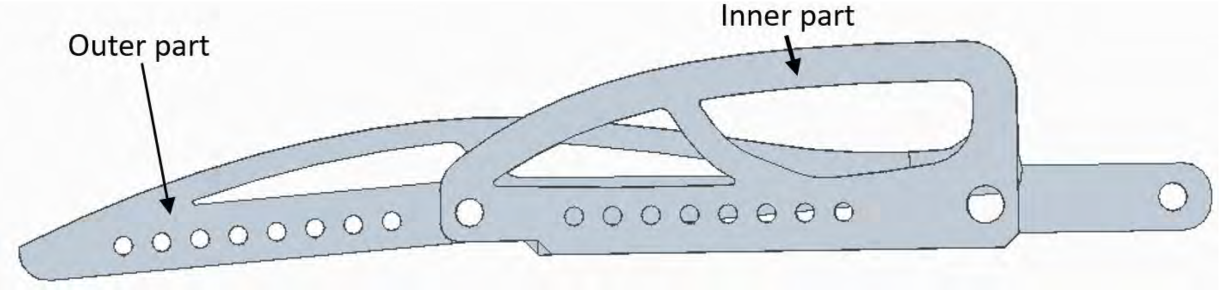

Figure 3.8: Model of finger joint (taken in solid edge)

3.2.2 Thumb

Similar to the constructed thumb on the robotic hand, simplifications of the thumb on the exoskeleton was required. Once again, the design could be compared to the finger parts, but with a different base and angle. However, it proved sufficient in order to mimic and simulate "hand-like" movements, for example grabbing something (Figure 3.9).

Figure 3.9: The potentiometers and back of hand (taken by authors)

3.2.3 Hand cover

The cover is the foundation placed on top of the hand. This cover connected the fingers with the wrist joints, whilst being the home for the several potentiometers controlling the robotic hand (figure 3.10). A protrusion that went from the cover down under the palm, was added in order to properly mount the cover onto the hand, while also allowing the cover to neatly follow the hand and wrist's rotation (Figure 3.11).

Figure 3.10: Hand cover

3.2.4 Wrist

A solution for registering the rotation of the wrist has been constructed by connecting two joints. One being able to rotate in the xy-plane and the other in xz-plane. These two joints act as the linkage between the hand and arm (Figure 3.11).

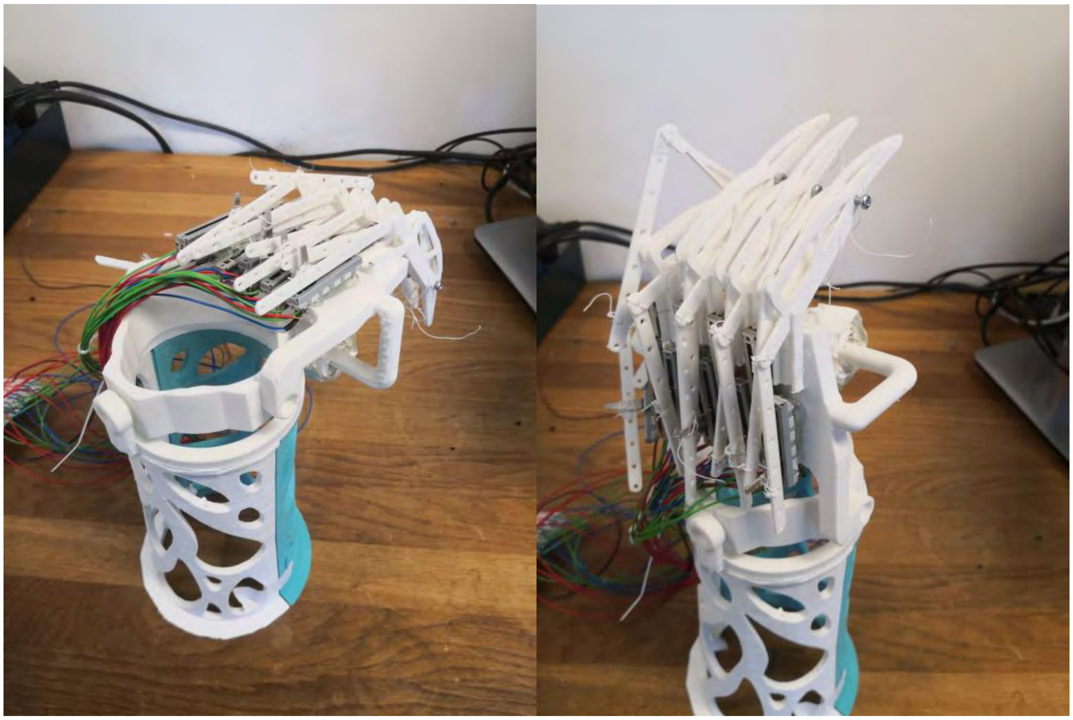

Figure 3.11: The wrist in its two extreme positions (taken by authors)

3.2.5 Forearm

In order to have stability in the exoskeleton an arm part was designed and constructed. This part is connected to the wrist parts and houses the breadboard with the circuits. Since it takes a lot of surface and material in order to have a part cover the entire arm, the arm was made with a web design, lowering the amount of required material and cutting down on print time (Figure 3.12). This solution has an impact on the structural integrity of the design, but since it is not meant to withstand any large forces, it was deemed to be an acceptable compromise

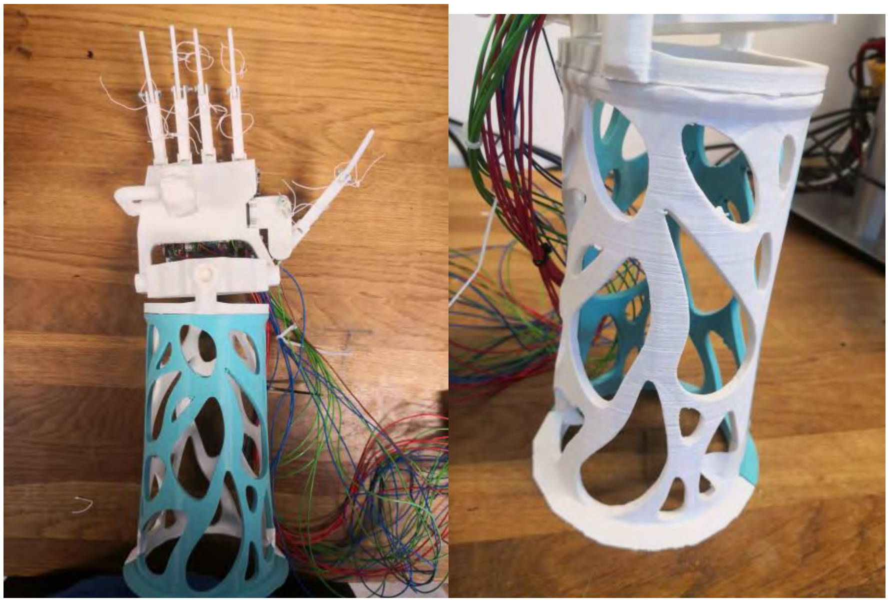

Figure 3.12: The forearm (taken by authors)

3.2.6 Electronics

The electronics consists of several potentiometers, which transmit the position of the fingers. These subsequently send the signal to the analog pots on the Arduino, which reads the signal. These signals are interpreted by the Arduino as a number between 0 and 1023. This signal is then rewritten as a number between 0 and 180, this is essential as the servos have a 0-180° operating angle. The program can now translate the position of the potentiometer to the servo and change its position correspondingly. As seen in Figure 3.13, the servos need a separate power supply rather than using the built in 5V port on the Arduino, this is due to the servos drawing more power than the port is able to handle. Note the use of rotational potentiometers in the diagram, this is due to the program not having linear potentiometers

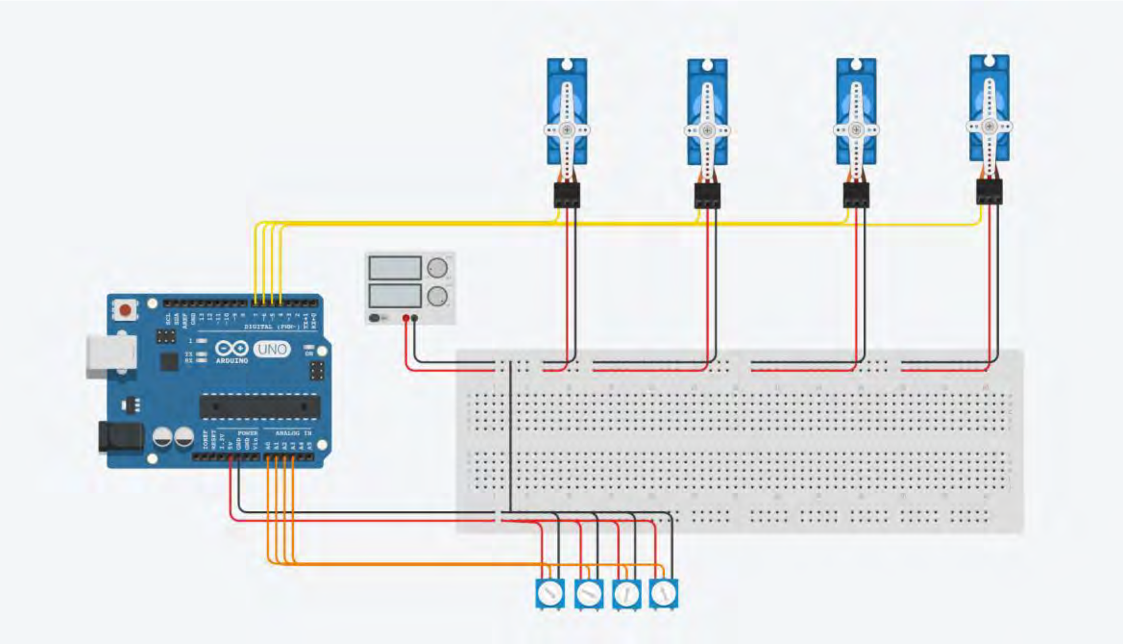

Figure 3.13: The wiring diagram (made in tinkercad)

4. Results

4.1. Design allowing for performance of simple tasks

Basic tasks such as pointing, grabbing an object and giving a thumbs up, could all be mimicked by a straight bending motion by the fingers and thumb. Pointing at something only requires one finger to stand in default position while the rest curls inwards all the way. In order to grab an object, the most important factor is the ability to pinch the object between the thumb and one or several fingers. This could be mimicked by angling the thumb inwards, so that, when curled, it would make contact with either the palm or another finger. Meanwhile, giving a thumbs up is more or less the same as pointing at something. The thumb remains in its default position as the other fingers curl inwards (Figure 4.1).

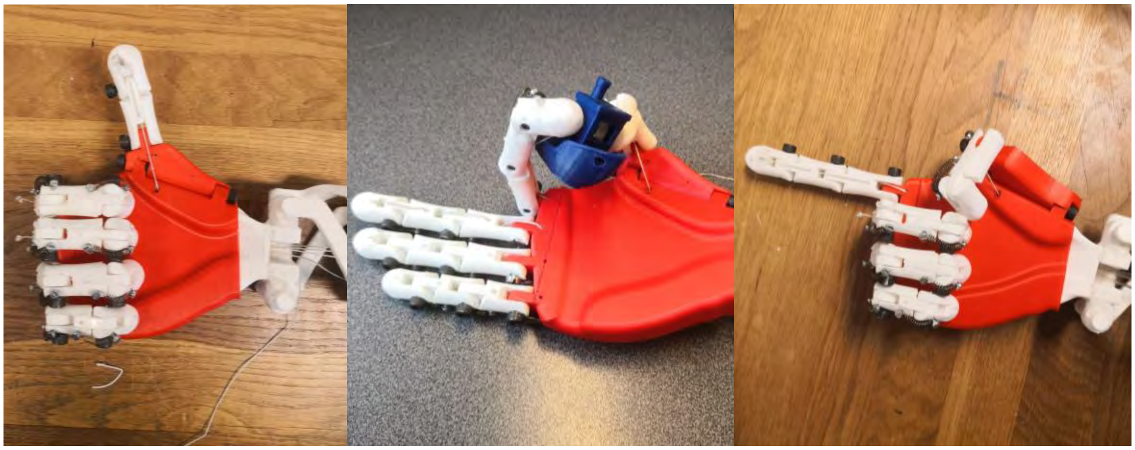

Figure 4.1: The hand performing some gestures (taken by authors)

The curling motion of the fingers are produced by string running through the fingers in a specific way (figure 4.2) that allows for two separately controlled curling motions. One in the inner part and one in the outer part. These strings could in turn be connected to servo motors that would tighten the string and force the fingers to curl. A counter force in order to return the fingers into an upright position was introduced by installing small springs on the back of the fingers (figure 4.3).

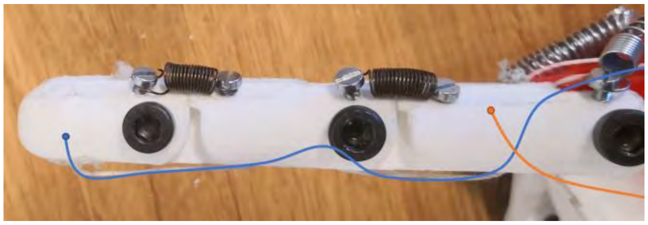

Figure 4.2: The springs and wires running through the finger (taken by authors)

Figure 4.3: Springs at the back of the fingers (taken by authors)

4.2. Transmitting motion from user to the robotic hand

In order to transmit the motions of the user, the robotic hand relies on an exoskeleton that has the ability to measure movements of the fingers (Figure 4.4). This is achieved by a two-part design that is strapped onto the user's fingers, which has the ability to rotate around the shared axis, and therefore not interfering with each other. This gives the robotic fingers a realistic and highly controllable motion, by controlling the bending of the fingers base joint and the second joint separately. The finger assemblies on the exoskeleton are in turn connected to one slide potentiometer each, that move as the fingers bend. The potentiometers are in turn connected to servo motors located in the robotic hand that pulls on strings that goes through the fingers.

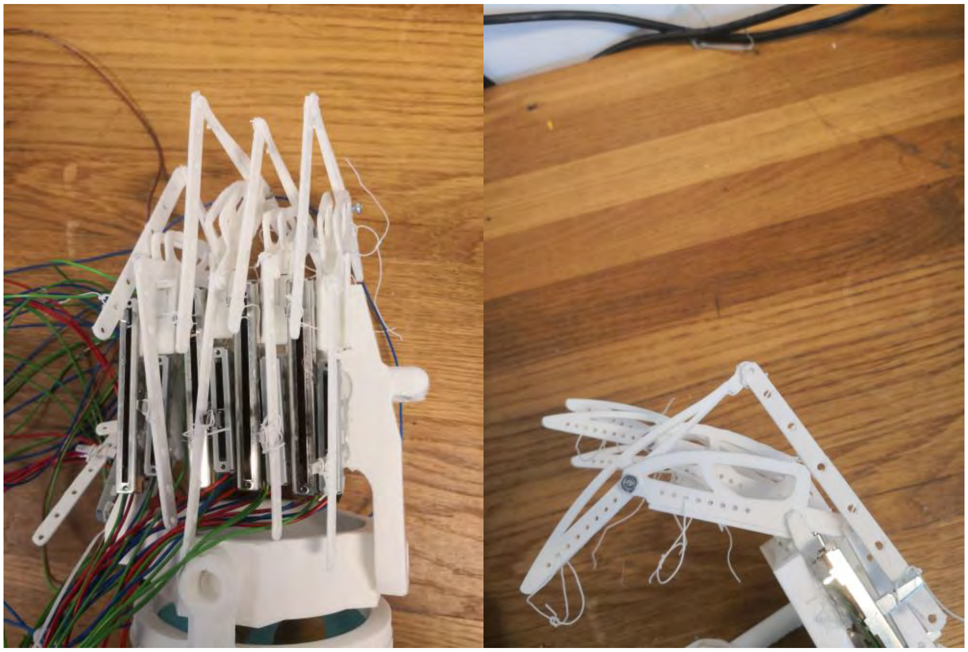

Figure 4.4: The finger assemblies (taken by authors)

4.3 System inaccuracy

During use of the exoskeleton, a slight inaccuracy between the angle of the user's finger and the robotic hand could be observed (Figure 4.5). Where the second joint showed a higher deviation throughout the motion. It can also be observed that the robotic fingers tended to go over the 90° when the user's fingers were at 90°. Furthermore, the second joint had a larger deviation at 30° and 45°.

User's finger angle of the first joint (°)	**User's finger angle of the second joint (°)**	**Robotic hand's finger angle of the first joint (°)**	**Robotic hand's finger angle of the second joint (°)**
0°	0°	2°	0°
30°	30°	28°	25°
45°	45°	40°	33°
90°	90°	93°	98°

Table 4.1: Comparison between user angle and robot angle

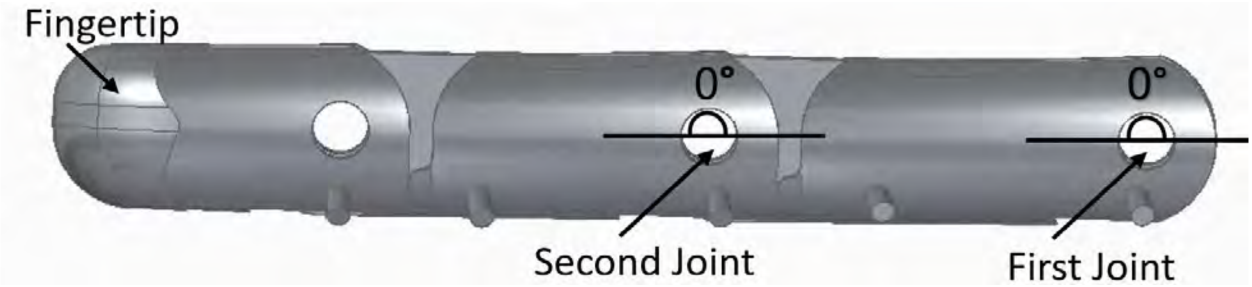

Figure 4.5: The finger joints at default position (taken in solid edge)

5. Discussion and Conclusion

5.1 Discussion

Since the design and control of the robotic hand is highly mechanical with a somewhat simplistic code, most of the problems and notable successes have been in the mechanical aspects of the final project.

The two parts that the exoskeleton fingers consisted of were connected partly by a 3D-printed frame, connecting the fingers to the hand cover, as well as a screw. The screw combined with the thin width of the finger parts resulted in poor stability. This gave the outer part of the fingers a tendency to bend to the sides. This both made it awkward for the user to control but also lowered the range of motion in the fingers. This problem could be resolved by adding small tubes around the screw on either side of the part, centering it in the middle and keeping it stable.

Due to a combination of minimal space between the fingers and a lack of time, a suboptimal solution was used to mount the exoskeleton fingers onto the user’s own fingers, where a string was used to tie it user and exoskeleton together. This was both very awkward while trying to fit the fingers through the string, as dealing with so many moving parts often resulted in entanglement or the breaking something. Furthermore, since it was hard getting all the strings properly tightened, especially when different users with different sized hands and fingers took turns at using the hand, the finger tended to slip up to the sides. This bent everything and hindered proper movement of the fingers. This could be solved by using a more rigid material instead of string. However, this proved more of a challenge than anticipated.

Due to the design of the exoskeleton there is not much space in between the fingers, meaning that a 3D-printed structure would risk not fitting in between. Discussions of adding velcro instead were had, but our budget wasn’t large enough. Velcro is both thin and sturdy enough to give the needed support for a proper and stable movement of the finger, without a tendency of slipping. Furthermore, the different shapes and sizes of the user's hands present a challenge while trying to design the exoskeleton. Both the finger length and shape of the hand made the design of the exoskeleton fingers and hand cover difficult. Since human hand sizes vary so much, there wasn’t really any uniform shape and size that could be designed in order to fit all fingers and hands. Designs with variable lengths and shapes of the parts were made, but with the short timeframe, no success was had in that area.

We quickly noticed that our potentiometers took a bit more space than anticipated. This resulted in it being slightly crowded on top of the hand cover on the exoskeleton. Which in turn resulted in some bad angles for the linkage between the exoskeleton fingers and the potentiometer, increasing the friction and negatively impacting the mobility.

The exoskeleton hand utilizes slide potentiometers to transfer the user's movements to the robotic hand. These are of linear scale and rotate the servo proportionally to the distance the potentiometers are moved. Two potentiometers of different length and resistance were used. The differences in length were necessary in order to accommodate for the different rotational radii in the exoskeleton's finger parts. Where the outer part, with a larger rotating radius, required a longer potentiometer in order to allow it to register the full motion when bending the outer part of the user's finger. Meanwhile the difference in resistance was a result of not being able to find a slide potentiometer with both the correct length and resistance. The length of the potentiometer was deemed more important, hence the difference in resistance. This however could have been the reason for a slight sensitivity difference between the two potentiometer models that was detected during testing. Furthermore, the number of potentiometers barely fit onto the hand, and a system with rotary potentiometers could be more space efficient.

Not all fingers are controllable since our budget didn't allow for servo motors for all the fingers. However, since all of the fingers are controlled in the same way they could all be tested with the existing servo and it could be concluded that they all would have worked given enough servos. Then with a higher strain on our battery pack with AAA batteries.

The robotic hand's ability to mimic a real hand was overall good, the fingers were able to bend very similar to real fingers. They were able to bend in all joints and could be controlled in two ways; at the bottom of the finger as well as the top two joints. This gave the robotic hand the ability to do hand-like movements like pointing, giving thumbs up, and even shaking a hand; though the handshake was somewhat awkward with it being both limp and firm at the same time. This is a result of the fingers sensitivity being slightly off as a result of the potentiometers not working as expected. Since human fingers can not only move up and down, but also wiggle a bit side to side, the movement was hindered when controlling the robotic hand with the exoskeleton. Though this aspect of motion was deemed too complex when the joints and foundations were being designed. With the current choice of using slide potentiometers in our design, the side to side movement of the fingers wouldn't be possible as a result of not having enough space for additional potentiometers.

The robotic hand's thumb is in turn very good at mimicking a real thumbs motion, even though it is heavily simplified. It lacks the ability to wiggle or rotate around its own axis, and can only bend inwards like the rest of the fingers. However, it turns out that this motion isn't essential when performing tasks such as grabbing objects. The thumb on the exoskeleton worked less than satisfactory. It fulfills its purpose since we did not intend for a design that could control all the different motions a real thumb can perform. But due to the surprising difficulty in making a hand cover that fits well on top of a hand (as a result of varying sizes of hands and its very flexible shape), the thumb part fits poorly on the user. It was angled wrong which made extended movements of the thumb restrictive. However, the user could move the thumb enough to move the connected potentiometer and therefore, with a bit of practice, the thumb on the robotic hand.

5.2 Conclusion

In summary, this thesis sought to answer questions in regard to human-robot interaction. We set out to create a biomimetic hand and accompanying motion tracking exoskeleton. Our goal was to the best of our ability, with some constraints, construct a robot which could as closely as possible mimic the function and dexterity of its biological counterpart. Large simplifications were made due to the human hand's astounding complexity. Along the way we encountered multiple problems, such as a limit in resources, limiting us to only being able to have a few functioning fingers. Despite these setbacks we were able to answer research questions such as "*How well does the design mirror the position of the user's finger?*".

We found that our hand could achieve several of the motions the humans can, it has enough dexterity and control to touch fingertips and hold small objects. The exoskeleton can detect finger position, although somewhat irregular, as well as transmit data to the hand enabling mirroring. Multiple improvements and solutions to problems have been identified and will be discussed below. When bending the fingers with angles between 0° and 90° it could be observed that while the first joint was accurate at transmitting the angle of the user's finger, the second joint was quite inaccurate. The second joint showed smaller angles when testing at 30° and 45° and overshot at 90°. This was most likely a result of a combination between different potentiometers with different resistance, as well as incorrectly tightened ropes and a difference in rotational radius at the exoskeleton's finger parts.

6. Recommendations and Future work

6.1 Recommendations

Use Velcro instead of string when attaching the user's fingers onto the exoskeleton. Also, make sure the potentiometers have the same resistance, this would make life easier as they would be equally sensitive.

6.2 Future work

In the future, the thumb could be developed into something more complex with more degrees of movement. This applies to both the robotic hand and the exoskeleton. For example, in order to allow the thumb on the exoskeleton to rotate around its own axis, it can be placed on a rotary potentiometer, in addition to the slide potentiometer that is in place in the current iteration.

Since this project originally was planned to be an entire robotic arm, a wrist design is connected to the robotic hand as well as to the exoskeleton, this can quite easily be controlled and by installing sensors or rotary potentiometers on the wrist joints on the exoskeleton, and servo motors connected to two of the three connecting arms on the robotic hand's wrist. However, all these extra potentiometer and servo motors would require Arduino Mega and a larger powerpack in order to work.

In order to make the exoskeleton more functional and comfortable, more work would have to go into making the hand cover fit well on the hand. For example, using a 3D-scanner to develop a cover from. A system accommodating the varying sizes of the user's hands and fingers would make the movement and use of the exoskeleton smoother. There are already some design implementations in place, like the holes in the exoskeleton finger parts, as well as some slidable foundation pieces for the fingers, but not enough to eliminate all of the problems. Lastly, the exoskeleton could be made portable by installing a transmitter in the exoskeleton and a receiver in the robotic hand.

6. References

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Appendix

Appendix A: Arduino code

Code inspired by Jun Tang on tinkerCAD

```
// Simon Stenberg Philip Linder-Aronson Mekatronik kex KTH 2021
#include <Servo.h>  //bibliotek för servomotor

Servo Tumme_servo;  // Skapar de olika servomotererna som objekt
Servo Pek1_servo;
Servo Pek2_servo;
Servo Lang1_servo;

int potpin_Tumme = 0;  // Deffinerar de olika analoga ingångarna där potentiometrarna är kopplade
int potpin_Pek1 = 1;
int potpin_Pek2 = 2;
int potpin_Lang1 = 3;

int Tumme_val;    //Skapar variabler för de analoga ingångarna
int Pek1_val;
int Pek2_val;
int Lang1_val;

void setup() {
  Tumme_servo.attach(7);  // Definierar utgångarna för servomotorerna
  Pek1_servo.attach(6);
  Pek2_servo.attach(5);
  Lang1_servo.attach(4);
}

void loop() {
  Tumme_val = analogRead(potpin_Tumme);          // Läser värdena av potentiometern och gert ett värde mellan 0 och 1023
  Pek1_val = analogRead(potpin_Pek1);
  Pek2_val = analogRead(potpin_Pek2);
  Lang1_val = analogRead(potpin_Lang1);

  Tumme_val = map(Tumme_val, 0, 1023, 0, 180);    // Skalar 0-1023 till 0-180 (röselsen av servomoteroerna i grader)
```

```
  Pek1_val = map(Pek1_val, 0, 1023, 0, 180);
  Pek2_val = map(Pek2_val, 0, 1023, 0, 180);
  Lang1_val = map(Lang1_val, 0, 1023, 0, 180);

  Tumme_servo.write(Tumme_val);                // Skickar det skalade värdet till servomotorerna
  Pek1_servo.write(Pek1_val);
  Pek2_servo.write(Pek2_val);
  Lang1_servo.write(Lang1_val);

  delay(5);                    // Liten delay så systemet har tid att uppdatera
}
```

Appendix B: Servo motor

Servo MS-6-40

BESKRIVNING

Servo i standardformat. Flera olika servoarmar medföljer.

Specifikationer:
* Axeltyp: Futaba 3F
* Storlek: 40.8 x 20.1 x 38mm / standard
* Hastighet: 0.18s / 60° (4.8V), 0.16s / 60° (6V)
* Vridmoment: 5kg/cm (69.56oz/in) / 4.8V, 6Kg/cm (83.47oz/in) / 6V
* Rotation: 120°
* Spänning: 4.8 – 6.0V
* Pulsbredd: 900 – 2100uS

Appendix C: Large potentiometer

Features

- Carbon element
- Metal housing
- 15-60 mm travel
- Single and dual gang
- Center detent option
- Dust cover option
- RoHS compliant*

BOURNS® PRO AUDIO

PTA Series - Low Profile Slide Potentiometer

Electrical Characteristics

Taper	Linear, audio
Standard Resistance Range	1 K ohms to 1 M ohms
Standard Resistance Tolerance	±20 %
Residual Resistance	500 ohms or 1 % max.
Insulation Resistance	Min. 100 megohms at 250 V DC

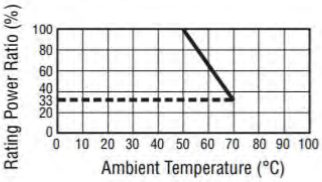
Environmental Characteristics

Operating Temperature	-10 °C to +50 °C
Power Rating, Linear	
15 mm	0.05 W (0.025 W Dual Gang)
20 mm	0.1 W (0.05 W)
30 mm	0.2 W (0.1 W)
45 mm	0.25 W (0.125 W)
60 mm	0.25 W (0.125 W)
Power Rating, Audio	
15 mm	0.025 W (0.015 W Dual Gang)
20 mm	0.05 W (0.025 W)
30 mm	0.1 W (0.05 W)
45 mm	0.125 W (0.06 W)
60 mm	0.125 W (0.06 W)
Maximum Operating Voltage, Linear	
15 mm	100 V DC
20-60 mm	200 V DC
Maximum Operating Voltage, Audio	
15 mm	50 V DC
20-60 mm	150 V DC
Withstand Voltage, Audio	1 Min. at 300 V AC
Sliding Noise	100 mV maximum
Tracking Error	3 dB at -40 to 0 dB

Mechanical Characteristics

Operating Force	30 to 250 g-cm
Stop Strength	5 kg-cm min.
Sliding Life	15,000 cycles
Soldering Condition	300 °C max. within 3 seconds
Travel	15, 20, 30, 45, 60 mm

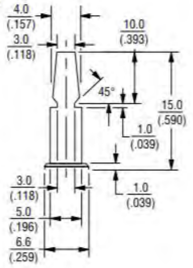
Derating Curve



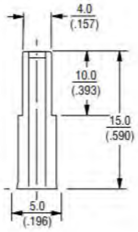
Lever Style & Product Dimensions

Actuator Styles

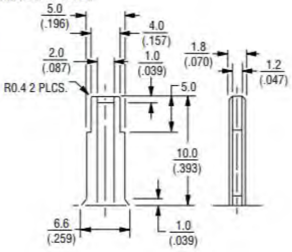
DP METAL LEVER



CP METAL LEVER



CI INSULATED LEVER



DIMENSIONS: MM / (INCHES)

How To Order

PTA 15 4 3 - 2 0 10 DP B 203

Model

Stroke Length
- 15 = 15 mm
- 20 = 20 mm
- 30 = 30 mm
- 45 = 45 mm
- 60 = 60 mm

Dust Cover Option
- 4 = No Dust Cover
- 5 = Rubber Dust Cover**

No. of Gangs
- 3 = Single Gang
- 4 = Dual Gang

Pin Style
- 2 = PC Pins Down Facing

Center Detent Option
- 0 = No Detent
- 2 = Center Detent

Standard Lever Length (See Table)
- 10 = 10 mm (CI Lever)
- 15 = 15 mm (DP, CP and CI)

Lever Style
- DP = Metal Lever (Refer to Drawing)
- CP = Metal Lever (Refer to Drawing)
- CI = Insulated Lever (Refer to Drawing)

Resistance Taper
- A = Audio Taper
- B = Linear Taper

Resistance Code (See Table)

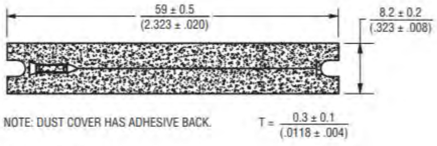
Other styles available.

** Part numbers with dust covers must be mounted with screws to a panel to prevent issues with the dust cover during usage.

Standard Resistance Table

Resistance (Ohms)	Resistance Code
1,000	102
2,000	202
5,000	502
10,000	103
20,000	203
50,000	503
100,000	104
200,000	204
500,000	504
1,000,000	105

Optional Dust Cover



NOTE: DUST COVER HAS ADHESIVE BACK.

T = 0.3 ± 0.1 / (.0118 ± .004)

*RoHS Directive 2002/95/EC Jan. 27, 2003 including annex and RoHS Recast 2011/65/EU June 8, 2011.
Specifications are subject to change without notice.
The device characteristics and parameters in this data sheet can and do vary in different applications and actual device performance may vary over time.
Users should verify actual device performance in their specific applications.

Applications

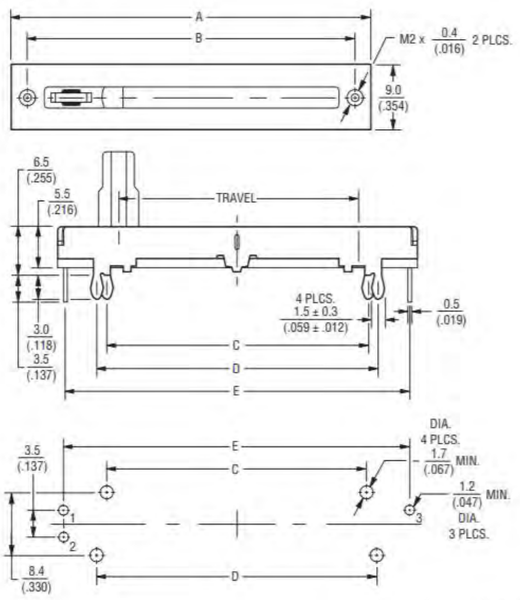
- Audio/TV sets
- Car radio
- Amplifiers/mixers/drum machines/synthesizers
- PCs/monitors
- Appliances

PTA Series - Low Profile Slide Potentiometer

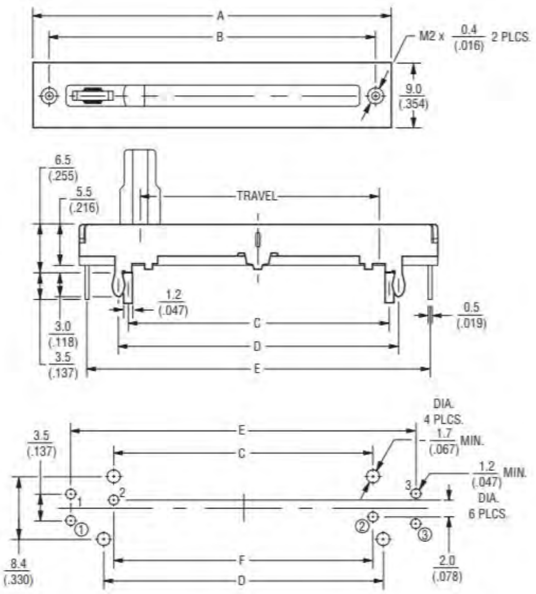
BOURNS®

Product Dimensions

PTAxx43



PTAxx44



DIMENSIONS: MM / (INCHES)

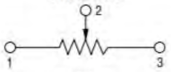
Single Gang Dimensions

Model	A	B	C	D	E	Travel
PTA1543	30 (1.18)	26 (1.02)	17.8 (.700)	20.2 (.795)	28.5 (1.12)	15 (.59)
PTA2043	35 (1.37)	31 (1.22)	22.8 (.897)	25.2 (.992)	33 (1.29)	20 (.787)
PTA3043	45 (1.77)	41 (1.61)	32.8 (1.29)	35.2 (1.38)	43.5 (1.71)	30 (1.18)
PTA4543	60 (2.36)	56 (2.20)	47.8 (1.88)	50.2 (1.97)	58.5 (2.30)	45 (1.77)
PTA6043	75 (2.95)	71 (2.79)	62.8 (2.47)	65.2 (2.56)	73.5 (2.89)	60 (2.36)

Dual Gang Dimensions

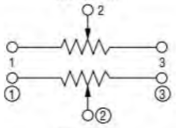
Model	A	B	C	D	E	F	Travel
PTA1544	30 (1.18)	26 (1.02)	17.8 (.700)	20.2 (.795)	28.5 (1.12)	18 (.708)	15 (.59)
PTA2044	35 (1.37)	31 (1.22)	22.8 (.897)	25.2 (.992)	33 (1.29)	23 (.905)	20 (.787)
PTA3044	45 (1.77)	41 (1.61)	32.8 (1.29)	35.2 (1.38)	43.5 (1.71)	33 (1.29)	30 (1.18)
PTA4544	60 (2.36)	56 (2.20)	47.8 (1.88)	50.2 (1.97)	58.5 (2.30)	48 (1.88)	45 (1.77)
PTA6044	75 (2.95)	71 (2.79)	62.8 (2.47)	65.2 (2.56)	73.5 (2.89)	63 (2.48)	60 (2.36)

SINGLE GANG



SCHEMATIC

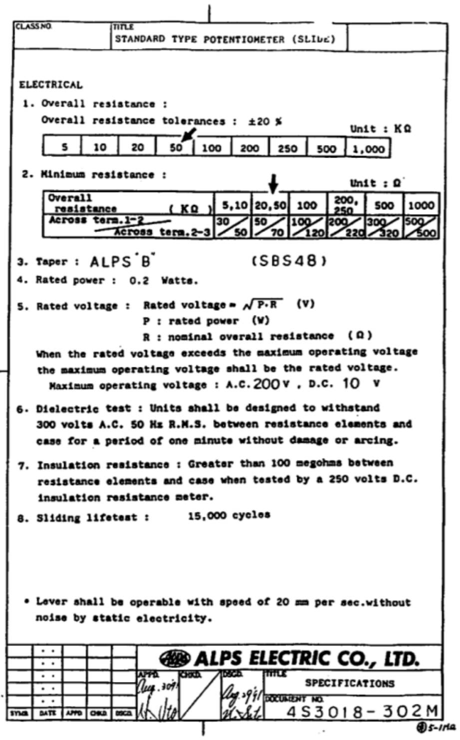
DUAL GANG



SCHEMATIC

REV. 12/14

Appendix D: Small potentiometer



CLASS NO.

TITLE
STANDARD TYPE POTENTIOMETER (SLIDE)

ELECTRICAL

1. Overall resistance :
   Overall resistance tolerances : ±20 %

Unit : KΩ

5	10	20	50	100	200	250	500	1,000

2. Minimum resistance :

Unit : Ω

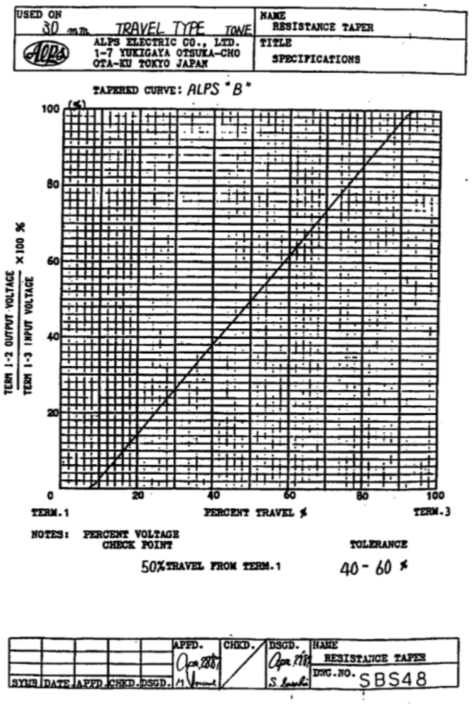
Overall resistance (KΩ)	5,10	20,50	100	200, 250	500	1000
Across term.1-2 / Across term.2-3	30 / 50	50 / 70	100 / 120	200 / 220	300 / 320	500 / 500

3. Taper : ALPS "B" (SBS48)
4. Rated power : 0.2 Watts.
5. Rated voltage : Rated voltage = $\sqrt{P \cdot R}$ (V)
   P : rated power (W)
   R : nominal overall resistance (Ω)
   When the rated voltage exceeds the maximum operating voltage the maximum operating voltage shall be the rated voltage.
   Maximum operating voltage : A.C. 200 V , D.C. 10 V
6. Dielectric test : Units shall be designed to withstand 300 volts A.C. 50 Hz R.M.S. between resistance elements and case for a period of one minute without damage or arcing.
7. Insulation resistance : Greater than 100 megohms between resistance elements and case when tested by a 250 volts D.C. insulation resistance meter.
8. Sliding lifetest : 15,000 cycles

- Lever shall be operable with speed of 20 mm per sec. without noise by static electricity.

ALPS ELECTRIC CO., LTD.

SYMB	DATE	APPD	CHKD	DSGD	APPD.	CHKD.	DSGD.	TITLE / DOCUMENT NO.
	· ·				Aug. 30 '91		Aug. 29 '91	SPECIFICATIONS
								4S3018-302M



USED ON
30 mm TRAVEL TYPE TONE

ALPS ELECTRIC CO., LTD.
1-7 YUKIGAYA OTSUKA-CHO
OTA-KU TOKYO JAPAN

NAME
RESISTANCE TAPER

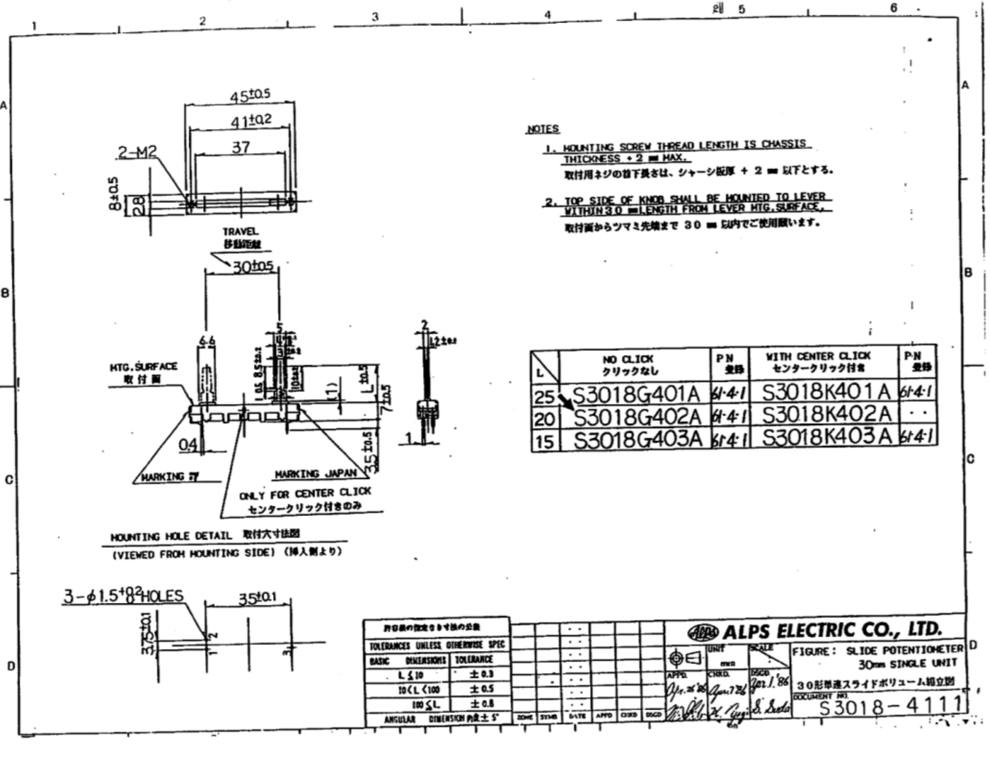
TITLE
SPECIFICATIONS

TAPERED CURVE: ALPS "B"

NOTES: PERCENT VOLTAGE CHECK POINT — TOLERANCE

50% TRAVEL FROM TERM.1 — 40 - 60 %

SYMB	DATE	APPD	CHKD.	DSGD.	APPD.	CHKD.	DSGD.	NAME / DWG. NO.
					Apr. 28 '87		Apr. 27 '87	RESISTANCE TAPER
					M.		S.	SBS48



NOTES

1. MOUNTING SCREW THREAD LENGTH IS CHASSIS THICKNESS + 2 mm MAX.
   取付用ネジの首下長さは、シャーシ板厚 + 2 mm 以下とする。
2. TOP SIDE OF KNOB SHALL BE MOUNTED TO LEVER WITHIN 30 mm LENGTH FROM LEVER MTG. SURFACE.
   取付面からツマミ先端まで 30 mm 以内でご使用願います。

L	NO CLICK クリックなし	PN 登録	WITH CENTER CLICK センタークリック付き	PN 登録
25	S3018G401A	61·4·1	S3018K401A	61·4·1
20	S3018G402A	61·4·1	S3018K402A	· ·
15	S3018G403A	61·4·1	S3018K403A	61·4·1

許容差の指定なき寸法の公差 TOLERANCES UNLESS OTHERWISE SPEC	
BASIC DIMENSIONS	TOLERANCE
L ≦ 10	± 0.3
10 < L < 100	± 0.5
100 ≦ L	± 0.8
ANGULAR DIMENSION 角度 ± 5°	

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ZONE | SYMB | DATE | APPD | CHKD | DSGD

UNIT mm | SCALE

APPD. Apr. 26 '86 | CHKD. Apr. 7 '86 K. | DSGD. Apr. 1 '86 S.

FIGURE : SLIDE POTENTIOMETER
30mm SINGLE UNIT
30形単連スライドボリューム組立図

DOCUMENT NO.
S3018-4111

Appendix E: Acumen

```
model Main (simulator) =  // Simon Stenberg Philip Linder-Aronson Mekatronik
kex initially
 x = 0, x' = 0.2, _3D=()    //Start varden
always
 x' = 0.13,               //Forandringsfarlopp
 _3D = (Box // Finger 1

size=(1,1,6) // Radie
color= red // farg
center=(2*x,-1,-0.7-2.2*(sin(x^2))) // Forflyttning av objekt
rotation=(0,x,0), // orienteing



Box //  Finger 2

size=(1,1,6)
color= red
center=(2*x,1.5,-0.7-2.2*(sin(x^2)))
rotation=(0,x,0),


Box //  Finger 3

size=(1,1,6)
color= red
center=(2*x,0.2,-0.7-2.2*(sin(x^2)))
rotation=(0,x,0),


Box //  Finger 4

size=(1,1,6)
color= red
center=(2*x,3,-0.7-2.2*(sin(x^2)))
rotation=(0,x,0),


Box // Tumme
```

```
size=(1,3,1)
color= red
center=(0,-3,-6)
rotation=(0,0,0),

Sphere //Knoge 1
size=(0.8) //Radie
color= black //farg
center=(-0.3,-1,-3.5) //position

Sphere //knoge 2
size=(0.8)
color= black
center=(-0.3,0.2,-3.5)

Sphere //knoge 3
size=(0.8)
color= black
center=(-0.3,3,-3.5)

Sphere //knoge 4
size=(0.8)
color= black
center=(-0.3,1.5,-3.5)

Sphere //knoge 5
size=(0.8)
color= black
center=(-0.3,-1.5,-6)

Box //handflata
center=(0,1,-6.25)
size=(1,5,5)
color=blue
rotation=(0,0,0))
```

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