University of Tartu
Faculty of Science and Technology
Institute of Technology

Elchin Huseynov

Design and Control of a Social Humanoid Robot - SemuBot’s Hand

Bachelor's Thesis (12 ECTS)

Curriculum Science & Technology

Supervisors:
Professor, PhD Alvo Aabloo
Leonid Zinatullin

Tartu 2024

Design and Control of a Social Humanoid Robot - SemuBot's Hand

Abstract

Children can find socialising difficult due to communication problems and a lack of comprehension of social cues[1], which can lead to isolation, marginalisation, and difficulties building social bonds. Social robots are an effective solution to this problem[2]. But, social robots need to be embodied as a humanoid for children to create a will to socialise with the robot. There are several versions of social humanoid robots. However, most are prohibitively expensive and difficult to repair because they're closed-source. SemuBot is one of the projects that aims to solve these issues and help tackle children's socialisation issues. Semubot is a student-led, nonprofit organisation. This work pertains to the arm and the forearm parts for the SemuBot. Natural interactions between machines and humans require the robot to display body language, requiring robotic hands. However, the hand designs that are currently available either have expensive and/or noisy actuation systems. Some also have insufficient degrees of freedom, limiting the number of gestures they can make. In this work, we present an open-source, modular hand with 7 actuated degrees of freedom. The design incorporates a bio-inspired tendon-driven actuation mechanism, which uses cost-effective materials and off-the-shelf components to achieve common hand gestures.

Keywords:

Human-robot interaction, Social humanoid robot, robotic hand design, Open-source robotics, Hand gestures

CERCS:

T115 Medical technology

T125 Automation, robotics, control engineering

T210 Mechanical engineering

Sotsiaalse Humanoidroboti Disain ja Juhtimine - SemuBoti Käsi

Lühikokkuvõte

Erivajadustega lastel võivad esineda probleemid sotsialiseerimisega, sest neil on raskused suhtlemisega ning neil raske mõista sotsiaalset konteksti[1], see omakorda võib tuua kaasa isolatsiooni, marginaliseerumise ja raskuseid sotsiaalsete sidemete loomisel. Sotsiaalrobotid on tõhus lahendus sellele probleemile[2]. Laste huvi haaramiseks peavad sotsiaalrobotid olema inimesele sarnase kehaga. On olemas mitmeid sotsiaalsete humanoidrobotite versioone, kuid enamik neist on kallid ja suletud lähtekoodi tõttu raskesti parandatavad. SemuBot on üks projektidest, mis püüab neid probleeme lahendada ja aidata sotsialiseerumisprobleemidega lapsi. SemuBot on tudengite juhitud mittetulundusühing. See töö käsitleb SemuBoti käelaba ja käsivarre osi. Loomulikud interaktsioonid masinate ja inimeste vahel nõuavad, et robot valdaks kehakeelt, mis eeldab, et robotil on žestikuleeriv käsi. Praegu saadaval olevad käed on kas kallid ja/või mürarikkad. Mõnedel puudub piisav liikumisvabadus, mis piirab nende poolt tehtavate žeste. Selles töös esitame vabavaralise, modulaarse käe, millel on 7 motoriseeritud vabadusastet. Käsi sisaldab bioinspireeritud kõõluse kaudu juhitavat mehhanismi, mis kasutab taskukohaseid materjale ja poest saadavaid komponente, et saavutada inimesele sarnased käeliigutused.

Võtmesõnad:

Inimese ja roboti suhtlus, Sotsiaalne humanoidrobot, Roboti käe disain, Avatud lähtekoodiga robootika, Käeliigutused

CERCS:

T115 Meditsiinitehnika

T125 Automatiseerimine, robootika, juhtimistehnika

T210 Masinaehitus

TABLE OF CONTENTS

TERMS, ABBREVIATIONS AND NOTATIONS

Actuator: A machine component responsible for moving or controlling a mechanism or system.

AI (Artificial Intelligence): The simulation of human intelligence in machines programmed to think and learn.

Arduino Nano: A small, complete, and breadboard-friendly board based on the ATmega328P microcontroller.

Degrees of Freedom (DoF): The number of independent movements a mechanism or robot can perform.

HRI (Human-Robot Interaction): The study of interactions between humans and robots.

Modularity: The design principle subdivides a system into smaller parts (modules) that can be independently created, modified, replaced, or exchanged.

PLA (Polylactic Acid): A biodegradable thermoplastic derived from renewable resources used for 3D printing.

PTFE (Polytetrafluoroethylene): A synthetic fluoropolymer of tetrafluoroethylene known for its non-stick properties, often used in tubing for guiding strings in robotics.

Servo Motor: A rotary actuator that allows for precise control of angular position, velocity, and acceleration.

Tendon-Driven Mechanism: A system that uses tendons (or strings) to control the movement of robotic limbs.

INTRODUCTION

In today's fast-evolving technology environment, robotics is making an impact in a number of fields, including socialising, education, and health. The creation of social humanoid robots for efficient and human-to-robot contact is one of the most fascinating uses of robotics. These robots offer a solution for many socially excluded people and aid in socialisation and communication, particularly with children with special needs. The main socialisation risks and obstacles children face include marginalisation, isolation, and an inability to form social links. This is due to the possibility that a child's social development and quality of life could be adversely affected by the inability of children with special needs to interact with their peers in an effective manner or by their inability to acquire important social skills. SemuBot, an Estonian project, aims to construct a social humanoid robot that is friendly, open-source, modular, and effective in interacting with children. This work is related to the arm section, and specifically, I focused on designing the hand and forearm parts of SemuBot.

The motivation of this thesis is significant in how it will help in the development of the SemuBot hand, which is dexterous, accurate, and naturally interacting. Robotic hands are extremely important in the ways that they make dexterity, precision, and natural interaction of machines with human beings possible. Current designs of most robotic hands are usually expensive, noisy, and often have hydraulic mechanisms, thus restricting movement. The aim of this thesis is to develop a working robotic hand that is not only accessible and adaptable but also free from these limitations.

1 Motivation

Engaging with people helps us understand our own identities, how we differ from others, and where we find our feeling of belonging in the world [3]. Humans are social creatures, and socialising is one of the natural needs of a human, especially a human in development - children. However, some children struggle with it because they do not believe in themselves, are shy, or have bad experiences. Overall, Environmental factors and genetic factors are the main factors that affect children's social development.

Children typically interact with their environment in various instances, such as school or kindergarten with their peers and teachers, at home with their parents, and during out-of-school time with their peer groups. These interactions influence their social skills, and this influence must be positive.

Regarding environmental factors, a notable illustration of the consequences of insufficient socialisation in children is the "Kaspar Hauser case". The boy, who was 16, had grown up in total isolation with inadequate nutrition and had been abandoned in Nuremberg. He could hardly walk and had a vocabulary of about 50 words when he was discovered neglected in 1828. The Kaspar-Hauser syndrome case serves as an example of extreme hospitalisation and the harmful psychological and physical consequences of acute social deprivation that are frequently linked to abuse [3]. “Kaspar Hauser case” is an extreme example. However, even non-extreme cases can cause serious problems that may affect an individual's future.

In terms of genetic factors, children inherit their biological parents' predispositions and temperaments, which have a substantial impact on their social development. These innate features, such as shyness or violence, combine with environmental influences to determine children's behaviours and social interactions. Understanding the interaction of heredity and environment is critical for addressing children's social development holistically and personalising interventions appropriately [1].

We can also see the linkage between genetic factors and environmental factors. As mentioned above, a shy parent may have a shy child because of genetics; the shyness of a parent may occur because of environmental factors. Hence, for healthy and positive future generations, there is a need to have a positive social life. Children are society's future, and their development, including the cultivation of socialisation skills, is critical for both their individual progress and society's overall well-being. There are various types of socialisation. The main types of socialisation that need to be improved in childhood are primary socialisation, secondary socialisation, formal socialisation, and emotional socialisation.

Primary socialisation - a child's balanced physical and mental growth is critical, and the family typically provides it until children are 7-8 years old. Primary socialisation involves learning behavioural norms, values, and regulations early on, building an individual's core informational and emotional framework.

Secondary socialisation - this type of socialisation is the time in which a kid interacts substantially with social contexts outside of the home. According to sociologists, this process continues throughout an individual's life, with a focus on purposeful personality development following primary socialisation.

Formal socialisation - though its scope is limited to officially recognised institutions, organisations, and bodies, formal socialisation is closely related to education. These organisations shape people's perceptions of societal norms and expectations by imposing particular goals, regulations, responsibilities, rights, and privileges [4].

Emotional socialisation - Parents help their children comprehend and express their feelings through emotional socialisation. Child behaviour issues, especially those about emotional development, are thought to be significantly influenced by this process [5].

Some children are having trouble with socialisation. There can be several reasons, such as finding it hard to talk to adults, to their peers, or being locked up to themselves. To solve this problem, they need to get help from therapists. However, therapists are also adults, so they can find it hard to talk to them. Another issue can be the need for more specialists in the field at some hospitals because of their locations or other reasons. Social robots are a great tool in such situations.

The novel field of social robot integration in paediatric speech and language therapy (SLT) is demonstrating encouraging outcomes in enhancing the communication abilities of individuals with disabilities. Studies demonstrate how well Socially Assistive Robots (SARs) may provide fun and helpful therapy environments, especially when these robots have conversational AI capabilities. Technical issues, restrictions on customisation, and high implementation costs are just a few of the challenges that still need to be overcome in order to improve their useful deployment in both clinical and home settings. [2]

1.1 Use Case of Social Robots

The use of social robots in different fields is in an increment. Social robots are important in healthcare. The reason for that is the cuteness of social robots which creates eagerness in children. Social robots have the potential to significantly improve children's human-to-human communication abilities. Interactiveness and entertainment of social robots during therapy is very helpful during therapy, especially for children struggling with speech. Pepper(*Figure 1*) is a good example of Social Robots. Pepper can get information from children and pass it to the doctors. In *Figure 6*, Pepper is assisting a child in developing communication skills by having a constructive conversation. Pepper is cute so children have a will to talk to it, as some children hesitate talking to doctors. Pepper can monitor and give real-time feedback to the doctors. It is quite helpful in medicine, however Pepper has some issues and being expensive and noisy is one of the main issues of Pepper. Furthermore, Pepper does not have enough computational power for implementing LLM and also Pepper's software and API is outdated.

Doctors complain about Pepper being noisy and would like to have a robot that can show hand gestures and can track patients with its eyes. Pepper is owned by Estonian firm and in *Figure 1* we can see an example.[2]

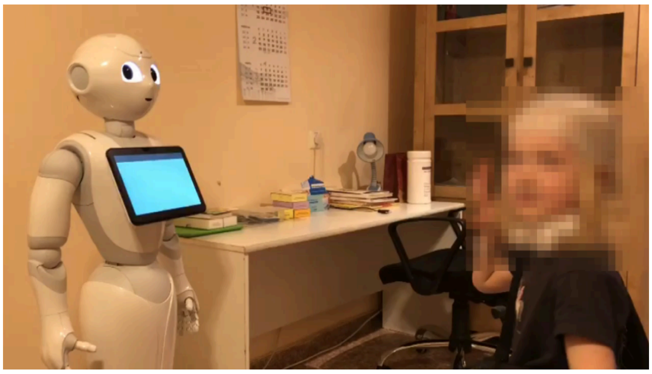


Figure 1. Pepper the Humanoid Robot Engages in Interactive Learning with a Child[6]

1.2 Requirements from End-user

There are different sections with requirements for a social humanoid robot from end users. In the following paragraphs, information regarding user requirements is given.

Row	**Requirements**	**Details**
1	Safety	Safety in interactions must be ensured in order not to cause a physical risk to children.[7]
2	User friendly	A social humanoid robot should be easy to operate by children and doctors or

		therapists, with a user-friendly interface, [8][appendix 1]
3	Interactivity	A social humanoid robot should communicate with users to initiate a conversation[appendix 2], facilitating intricate multitouch exchanges that promote the growth of social skills.[7]
4	Data Privacy	User data must be protected, privacy rules and regulations must be followed, and session data management must be kept private.[8]
5	Feedback Mechanism	A social humanoid robot should be able to provide users and therapists with real-time feedback. [7]
6	Visual aid - Cuteness	The social robot must look cute, as it enhances the communication level between a social humanoid robot and its users.[8]
7	Gestures	A social humanoid robot must be able to show gestures, which helps to increase socialisation and communication levels between a social robot and users.[7]
8	Audio aid	Social robots should have a cute voice tone and a well-hearable audio sound level because of their importance in communication.[8]
9	Sound level: less than 30dB	Actuation of robotic parts should be less than 30 dB. A voice level of less than 30 dB is regarded as quiet. High decibel levels can impede conversation and disturb users.[7]

10	Durability	The robot must have a durable design and battery life to ensure that it can withstand a paediatric environment. [8]
11	Adaptability and emotive interaction[appendix 2]	A social humanoid robot must be able to read users' emotions and, respond with corresponding emotions, and adapt to different situations.[7]
12	Database	The software should have the capability to store the child's name and other general information. Additionally, it should allow for the addition and modification of protocols, which are the session content plans.[*Appendix 1*]
13	Movement[appendix 2]	The robot must move at a human-like speed.
14	Tracking eyes[appendix 2]	The robot's eyes must be able to track eyes and have eye contact.

Table 1. Requirements for a social humanoid robot by the end user.

Social robots are vital in terms of gathering information from patients, especially from children and passing it to the doctors. However, social robots have to meet some requirements, which are given in *Table 1* with the details. Its user requirements highlight how it may improve children's social and communication abilities, especially in therapeutic environments. Essential requirements state that a social humanoid robot should interact with kids as a conversation partner rather than merely a toy. This entails projecting an approachable and amiable image, exhibiting responsive actions, and having a reassuring voice. The robot is meant to interact with children in a natural way; it has fluid language transitions and engaging, sympathetic gestures that cater to their need to feel safe and understood.[*appendix 1*]

2 Prior art

In this chapter, information regarding humanoid robots is provided.

2.1 Social Humanoid Robots

Humanoid is a robot which mimics humans in appearance and functionality. Humanoids are used in different applications, including healthcare. In healthcare, there are two types of humanoid robots. They are the ones that help in clinical applications and the ones that do not help in clinical applications. In our case, we need a humanoid robot for non-clinical applications, because we need to improve children's human-to-human relationship and humanoids are an excellent choice of robot for these applications. Humanoids, which are part of non-clinical applications, are usually social robots. Since our main problem, which needs to be solved, is the socialisation of kids, a social humanoid robot is a great choice. It has been seen that social humanoid robots are helping patients with autism. A vital communication tool, the gaze can convey feelings of anger or threat and has a profound effect on behaviour. [9]

In one experiment, university students participated in a game called "shell-game" in order to observe how various gaze types affected behaviour at different levels of difficulty. The results demonstrated that student behaviour varied depending on the level of difficulty. [10]

Although the use of humanoid robots has significantly improved the conduct, communication, and joint attention of autistic people, it has had less of an impact on the cooperative behaviour of patients. [10]

The interactions between students and robots were recorded during a research session. The students responded to the robots' commands, whether they were given or not, although the results did not notably differ. [10]

Through the use of humanoid robots, students gained a thorough understanding of autism management. Additionally, an investigation showed that robots might improve human-robot interaction, which in turn could improve patients' learning capacities. [10]

From the example mentioned above, human-to-humanoid-robot relationships can help in healthcare. There are different existing social humanoid robots that are being used in applications.

Reachy (*figure 1(a)*) is a humanoid robot designed for social interactions and research purposes. It is equipped with expressive capabilities, making it suitable for tasks that require human-robot interaction. Reachy is an affordable option for applications that involve social engagement. [11]

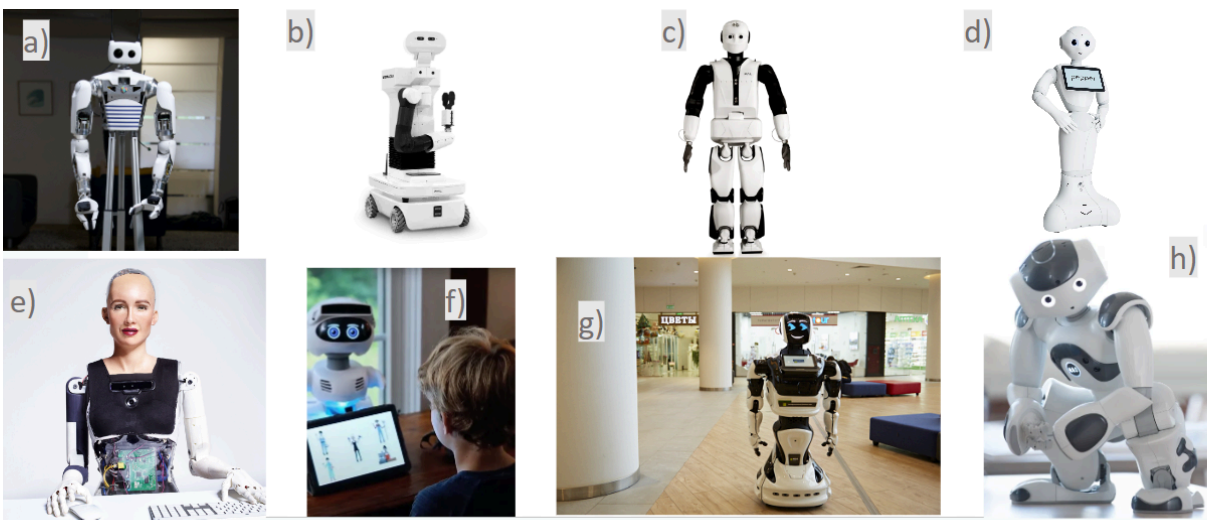


Figure 1. Social humanoids; a) Reachy [11]; b) Tiago[12]; c) Reem-C [13]; d) PEPPER [14]; e) Sophia [15]; f) Misty [16]; g) Promobot [17]; h) NAO [18].

Another humanoid robot is the TIAGo Mobile Manipulator Robot (*figure 1(b)*). TIAGo is designed for a variety of applications, including research and industry. However, TIAGo is not primarily intended for social interactions. [19]

Reem-C (*figure 1 (c)*) is a social humanoid robot made by PAL Robotics. It has 68 DoF. The robot can grasp, walking, whole-body control, and text-to-speech functionalities. [20]

Another semi-humanoid robot made by SoftBank Robotics is called PEPPER (*figure 1 (d)*). PEPPER is also an assistant robot that can collect data. This robot is closed-source, which makes it non-repairable. In terms of showing gestures, it has five fingers on each hand. However, the index finger does not have 2 degrees of freedom, which does not let it show all the hand gestures. Furthermore, this robot is loud, which end users do not want. [21]

Sophia (*figure 1 (e)*) is a humanoid robot made by Hanson Robotics. Sophia is an Innovation Ambassador for the United Nations Development Programme, which makes her its first kind. This robot is capable of performing human-robot interactions. However, Sophia does not seem cute, which makes it unsuitable for use as a social robot that works with children. [22]

Misty (*figure 1(f)*) is a social humanoid robot designed to interact with children and assist in educational and therapeutic settings. Misty's cute and approachable design makes it suitable for engaging with kids and helping with tasks such as socialisation and learning. This robot's features make it an excellent choice for non-clinical applications involving children. However, robot is closed-source, which means unrepairable.[23]

Promobot (*figure 1 (g)*) is a social humanoid robot which can work as a medical assistant. It can measure temperature, blood sugar, and blood pressure levels, and it also gives health recommendations. This robot is closed-source and non-repairable. [24]

NAO (*figure 1 (h)*) is a social humanoid robot made by SoftBank Robotics, which is an assistant for different organisations, mainly in Education and healthcare. The robot costs[25] around 11k euros. However, this robot is closed-source, which means it is unrepairable and needs to be sent to the producer for repair. [26]

Additionally, the social humanoid robots mentioned above have insufficient computational power, which is a big drawback as LLM cannot be implemented, and this limits these robots' emotive interactivity and adaptability.

3 SemuBot

SemuBot is an open-source social humanoid robot that is being developed in Estonia. It is intended for paediatric rehabilitation and aims to help kids who struggle with socialisation. SemuBot will provide a low-noise operating environment and pose no physical risks for

youngsters, thereby guaranteeing safety and ease of use. It will incorporate elements like showing gestures, and an onboard screen to display visual content in an effort to engage and excite children through lighthearted interactions. Additionally, the robot's design will make it simple to use and intuitive for therapists, needing no technical expertise and enabling quick modifications during sessions to enable a smooth incorporation into therapy sessions. SemuBot's operational architecture will ensure it can run continuously for several hours at a single charge and will save essential information like user identities and session protocols, which are necessary for tailored interactions during therapy. Furthermore, large language models will be used to enable the robot to have a conversation. Together, these specifications guarantee that SemuBot not only improves the therapeutic process but also contributes to the general growth and welfare of the kids it supports.

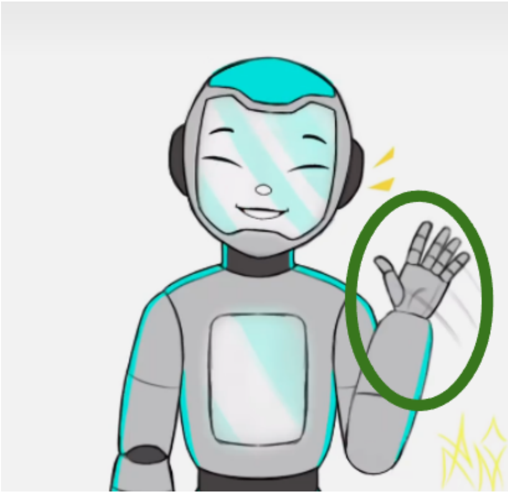


Figure 2. An illustration of SemuBot [Appendix 3].

The robot's hand component is crucial; it enables hand gestures and more interactive activities like using tools or playing games, making therapy sessions more engaging and effective for language learning.

Students have collaborated together in different sections like electronics, mechanics, design, programming and contributed to the project having a first prototype of SemuBot. SemuBot's initial prototype is centred on learning fundamental interactive features that are necessary for successfully engaging kids. The capacity to exhibit hand signals and move the head and eyes in response to noises are important characteristics that help draw in and hold the attention of children. Although object grabbing is not included in the first prototype, this capability is acknowledged as useful for future improvements, which could increase the robot's interaction potential. Additionally, SemuBot has a base with wheels which allows the robot to move around the room.

The work division between students is as follows: appearance, electronics, arm, wheels and base, head, body and neck.

The arm is also divided into two parts: the part from shoulder to forearm and the hand with the forearm. I did the very first prototype of hand with the section shown in *Figure 2*, the part of the arm inside the green circle represents the part I am responsible for.

3.1 SemuBot’s Hand Requirements.

T*able 2* contains requirements for SemuBot’s hand developed while the process of doing the project.

Row	Requirement	Specification
1	Hand gestures	Capable of showing hand gestures(*Figure 3*)
2	Degrees of Freedom	Index finger and thumb must have 2 degrees of freedom
3	Weight	Less than 1 kilogram
4	Open-source	Must be open-source[27]
5	Modularity	Fingers and motors can be customised and replaced
6	Forearm Size	Compact, with a diameter of 8 cm or less
7	Price	It should cost less than 500 euros
8	Sound Level	Operating noise level less than 30 dB
9	Proportionality	Proportional to other parts of SemuBot

Table 2. Requirements for SemuBot's hand.

The ability to show hand gestures is crucial for SemuBot, as it is a social humanoid robot. Hand gestures play a key role in socialisation and enhance the robot's appeal by making it appear more engaging and approachable. The required hand signs are shown in *Figure 3*.

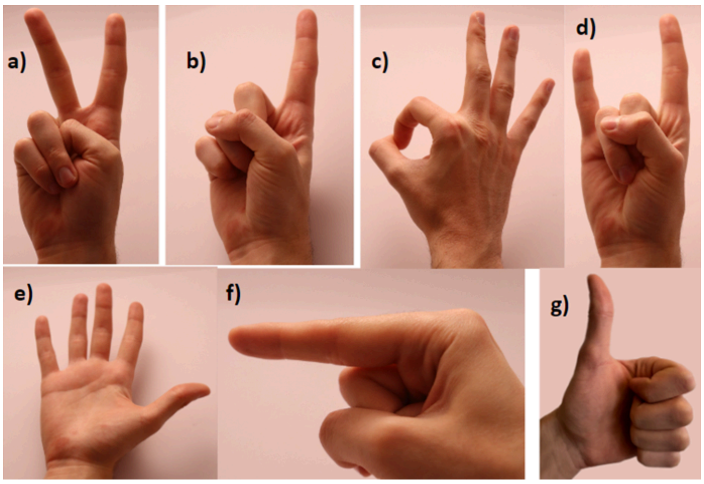
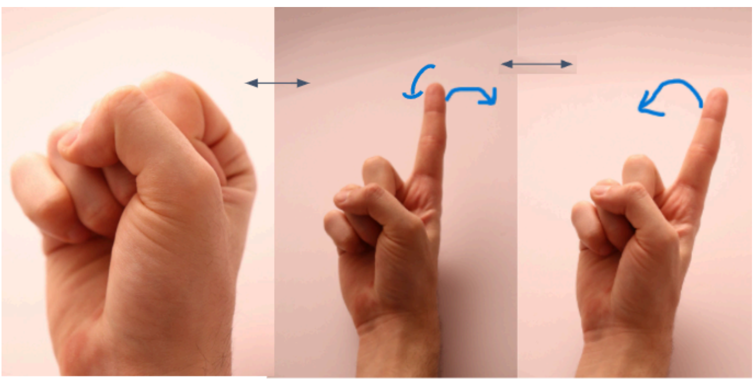


Figure 3. Hand signs.



The index finger and thumb of SemuBot must each have 2 degrees of freedom to fully and accurately display all hand gestures. For example, the hand sign shown in

Figure 4. Illustration of 2 degrees of freedom on the finger.

Figure 3 (a) cannot be shown without having 2 degrees of freedom in the index finger. This range of motion is essential for the robot to perform the intended gestures correctly, as illustrated in *Figure 4*.

SemuBot's hand should weigh less than 1 kilogram(*Table 2, row 3*) to ensure ease of movement. It connects to the robot's elbow, which is operated by a separate motor. Keeping the hand lightweight facilitates smoother and more efficient motion.

SemuBot's design should be open-source(*Table 2, row 4*) to facilitate easier repairs and modifications. This approach allows users and third parties to address and fix issues themselves, avoiding the limitations and delays often associated with repairs handled exclusively by the original manufacturers.

Modularity(*Table 2, row 5*) in SemuBot's design means that its parts can be easily replaced. This characteristic is beneficial as it simplifies repairs and maintenance, allowing for quick and efficient part replacement whenever necessary.

A thick or overly long forearm could detract from the appearance of SemuBot, a social humanoid robot, where aesthetics play a crucial role. Maintaining a compact forearm(*Table 2, row 6*) design is essential to preserve the robot's appealing and approachable look, which is vital for its effectiveness in social interactions.

The affordability(*Table 2, row 7*) of robotic hands is crucial, and this sometimes entails the use of less expensive materials that occasionally may result in lower quality. However, with improvements in material science and production processes, robust robotic hands can be produced for less than 500 euros without compromising functionality.

Keeping the sound level(*Table 2, row 8*) below 30 dB is crucial for SemuBot, as higher noise levels can be irritating to users. A quieter operation helps maintain the robot's charm and appeal, ensuring it remains endearing and acceptable in social interactions.

Ensuring that the hand is proportional(*Table 2, row 9*) to the other parts of SemuBot is important for maintaining a harmonious and aesthetically pleasing appearance. This proportionality is crucial in enhancing the robot's overall visual appeal, which significantly impacts its effectiveness as a social humanoid robot.

4 Overview of Existing Robotic Hands

Dexhand is an open-source humanoid robot hand (*appendix 5*). This robot hand is semi-dexterous and fast. The main issue in the usage of this hand is its sound. Dexhand is noisy, and fingers are not bending enough to show hand signs because of the bearings placed at the bottom of the fingers unless we ignore its bending degree and accept it as “bent”. Its fingers have 2nd degree of freedom. Dexhand uses a tendon-driven mechanism, and motors are attached to the palm and the forearm. [28]

The shadow hand is a dexterous hand that can perform multiple tasks, such as showing signs and grabbing items. It is developed in the UK by Shadow Robot Company. However, this robotic hand is too costly to use as a social humanoid robot. It has a cost of 4k-14k euros per degree of freedom and can have a maximum of 7 degrees of freedom. [29]

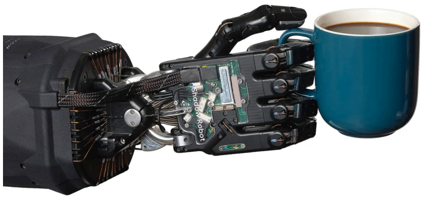


Figure 5. Shadow hand. [30]

ILDA hand displays the integration of linkage-driven systems for dexterous manipulation. The motors of this hand are attached to the hand palm, and all of its fingers have six-axis force/torque (F/T) sensors, which allow it to crush cans and grab an egg without crushing it. Although having a sensor is advantageous for this robotic humanoid hand, having motors on its palm is a drawback as it makes the hand palm thick. Another issue for this hand is related to its mechanism. In the linkage-driven finger mechanisms, the size of the finger matters. Fingers must be narrow in order to avoid having issues performing tasks, which makes this hand customisable in different ways. [31]

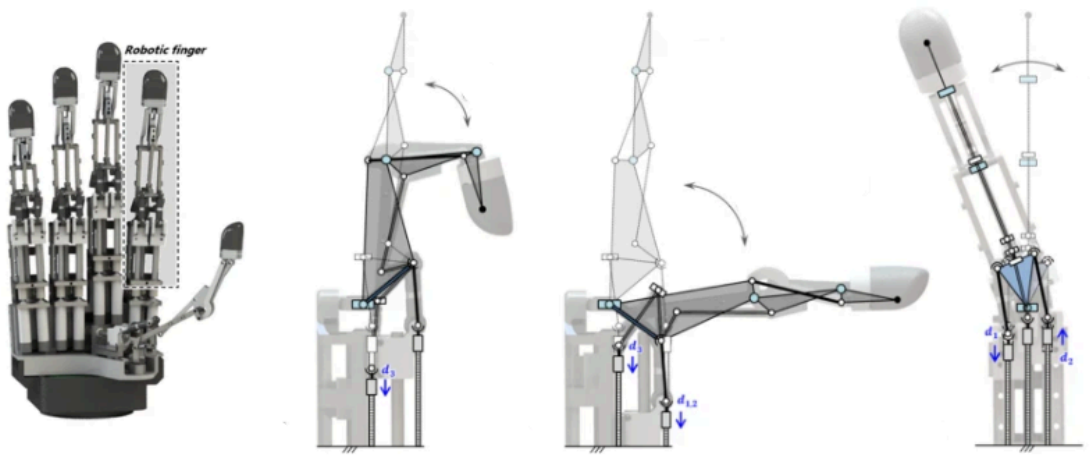


Figure 6. ILDA hand[31]

The other hand is from the article called “A Robot Hand Driven by Hydraulic Cluster Actuators” by Tianyi Kang, Hiroshi Kaminaga and Yoshihiko Nakamura. As an actuator, the robotic hand, which weighs 0.8kg, uses a hydraulic circuit actuation system. There is a 5-pump cluster, which they use to move fingers separately. The issue with the hands that use a hydraulic actuation system is that it makes the system too loud, and it cannot be used on social robots.[32]

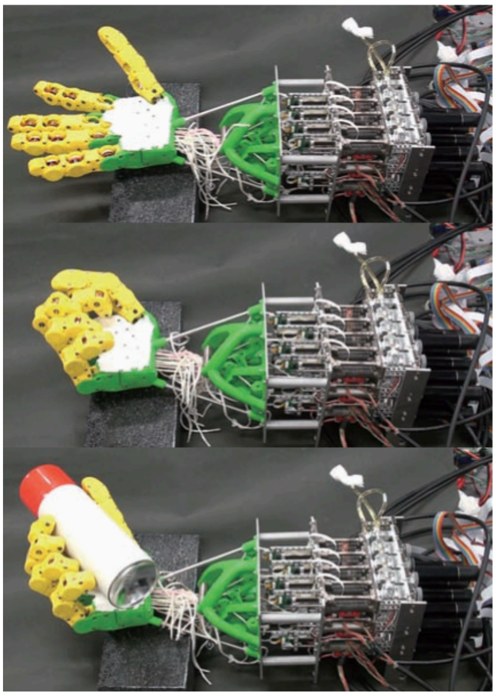


Figure 7. Hydraulic circuit actuated robotic hand

In Table *3*, you can see the comparison between robotic hands, which are already available.

Row	**Existing prototypes**	**Mechanism**	**Open-source**	**Low Price(Under 500 euros)**	**Sound level under 30dB**	**At least 2 degrees of freedom on index finger and thumb**	**Weight (kg)**	**Modular**
1	DexHand[28]	Tendon-driven mechanism	Yes	Yes	No	Yes	1.4 kg	Yes
2	ILDA hand[31]	Linkage-drive mechanism	No	No information	No information	Yes	1.1 kg	No
3	Shadow hand[29]	Tendon-driven mechanism	No	No	No information	Yes	4.3 kg	Yes
4	Hydraulic circuit actuated robotic hand[32]	Hydraulic circuit actuation mechanism	No	Yes	No	No	3.3 kg	No

Table 3. Comparison of different robotic hands

5 Methodology and Materials of SemuBot's hand

SemuBot's hand parts are 3D printed and Bambu Lab X-1(*Figure 8 (a)*) Carbon has been used for 3D printing parts that take time like palm, including small parts that are printed collectively. Bamu Lab X-1 Carbon(*Figure 8 (a)*) is much faster than Prusa Slicer (*Figure 8 (b)*) in the process of 3D printing. Prusa Slicer (*Figure 8 (b)*) is effective for printing small pieces as it has less calibration time.

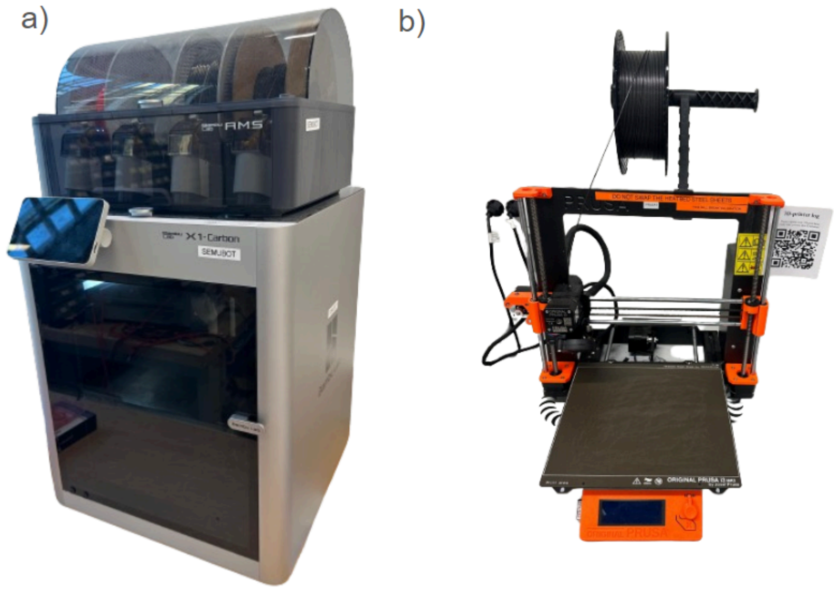
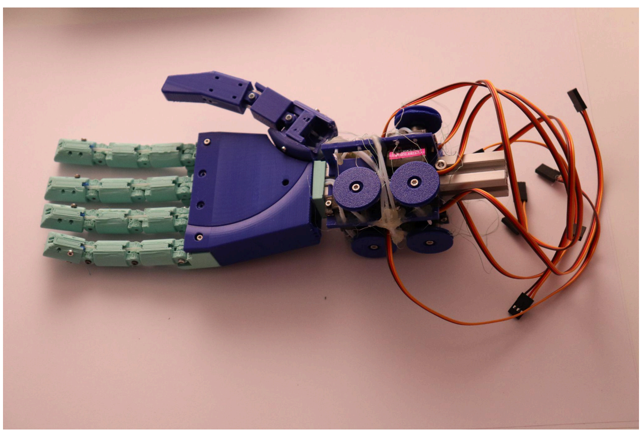


Figure 8. a) Bambu Lab X-1 Carbon printer b) Prusa Slicer.

In terms of programming, code scripts are written for Arduino Nano and Servo motors accordingly, in C++ and Python environments. For C++ which is written for Arduino Nano, Arduino Integrated Development Environment is used. To simplify control over servo motors Servo library is used in C++. For Python, Visual Studio Code Integrated Development Environment(IDE) is chosen, however different IDEs can be used. Pyserial time is used to manage serial communication between servos and Arduino Nano.

6 SemuBot's hand

6.1 SemuBot's Hand Design



In *Figure 9*, the first prototype of SemuBot's hand is shown. The initial prototype of SemuBot's hand is designed to mimic the gestures of a human hand.

Figure 9. First prototype of SemuBot's hand.

The fingers of SemuBot's hand are categorised into two groups based on their degrees of freedom:

- **Group 1**: Includes the thumb and index finger, each with two degrees of freedom.

- **Group 2**: Comprises the middle finger, ring finger, and little finger, each with one degree of freedom.

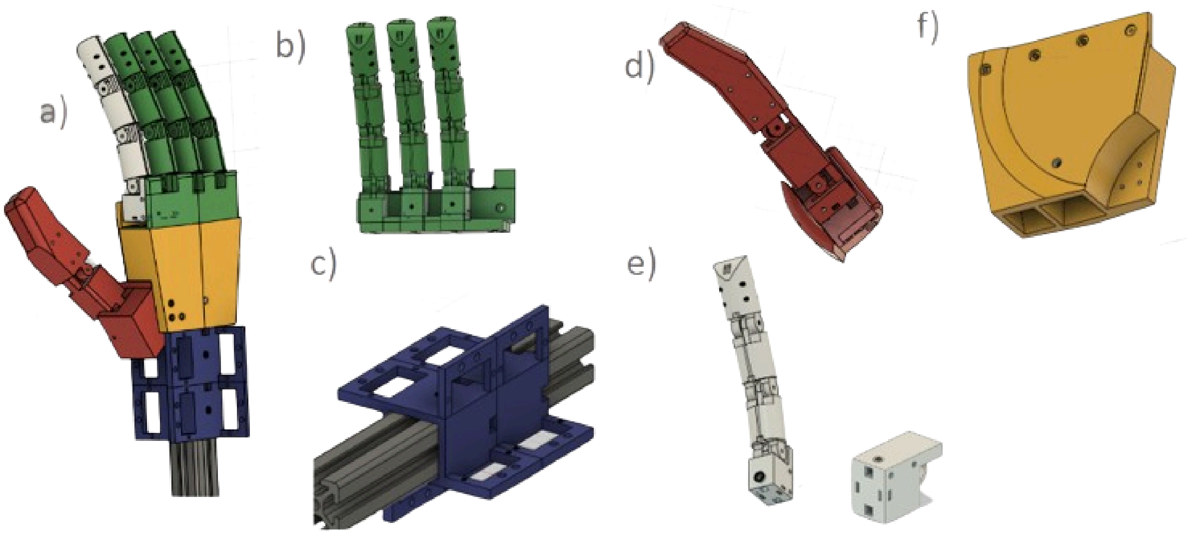


Figure 10. SemuBot's hand structure; a) Full Hand Assembly: The overall structure of SemuBot's hand; b) Group 1 fingers and connection module to the palm assembly; c) Motor Shell: Housing for the motors; d) Thumb and connection module to the palm assembly; e) Index finger; f) Palm

In *Figure 10* SemuBot's hand structure and assemblies are shown. In *Figure 10 (b)* the assembly of group 2 fingers with their connection module to palm is shown. In *Figure 10 (e)* the assembly of the index finger with its connection module enables one more degree of freedom, which helps to do the movement to sides shown in Figure 4. In *Figure 10 (c)* the shell of motors is shown, where PTFE tubes are glued with a hot glue and motors are placed. In *Figure 10 (f)* the palm section of hand is shown.

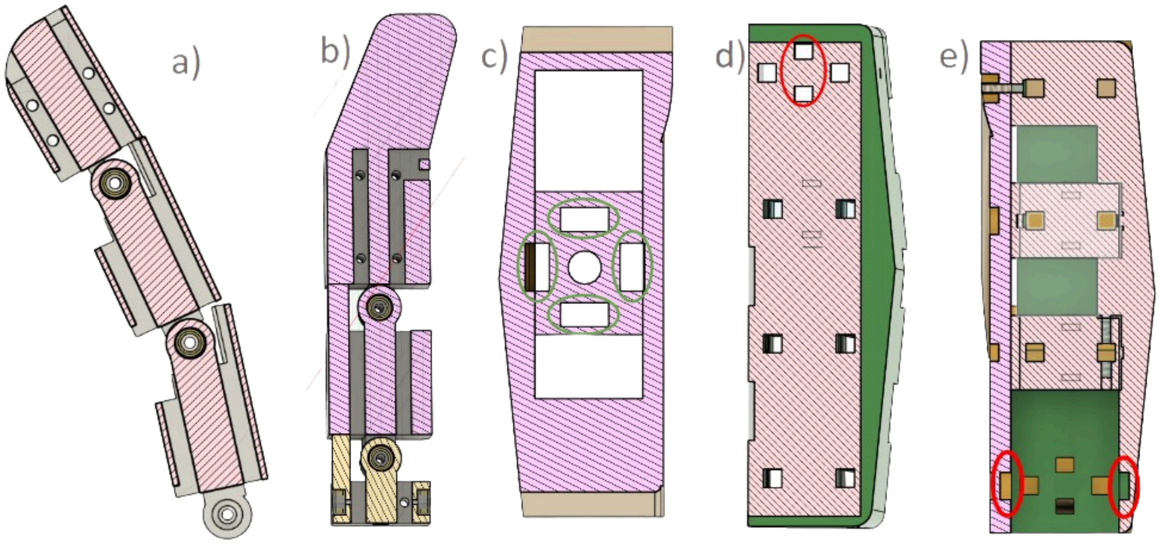


Figure 11. Section view of figures; a) Section view of fingers(except for the thumb) from left; b) Section view of thumb from right; c) Section view of palm from the bottom; d) Section view of Connection module of finger to palm from the palm side; e) Section view of Connection module of finger to palm from the fingers side.

In *Figure 11* (*a*) and *Figure 11 (b)* section views of fingers are shown. At the joint of the limb, there is a bearing that allows the limbs to bend. For tubes to go through, there are 3X3 mm holes in the limbs. The assembly of the index finger, which is shown in *Figure 10 (e),* is being attached to the bearings, which are being added to the holes shown in red in *Figure 11(e),* and the connected assembly can be seen in F*igure 10(a)*. *Figure 10 (b)* shows that group 2 fingers are attached to the connection module. In *Figure 11(d)* section view of the connection module of fingers to the palm is shown. There are holes for the PTFE tubes to be glued with a hot glue. The holes inside of red ellipses are for the strings which are designed for adding one more degree of freedom to the index finger. In *Figure 11(c)* there are four holes shown with green ellipses for PTFE tubes to extend from the palm to the motors' section and an illustration of it can be seen in *Figure 12*.

Fingers in group 2 are the little finger, ring finger and middle finger. Group 2 fingers assembled with the connection module to the palm are shown in *Figure 11 (b)*. Group 2 fingers can only fold and unfold. They cannot move to the sides. Each joint has 1 degree of freedom. They have holes, which are shown in *Figure 11 (a)*, for strings and silicone tubes. There are also screw holes in the upper limb for silicone tubes to be fixed. Silicone tubes are essential to avoid strings getting stuck in joints. Joints include bearings which enable folding and unfolding functionalities for the limbs and fingers. Fingers are in a slightly bent position, and the reason for that is to avoid fingers getting locked, which could happen as there are 3 degrees of freedom and one motor which is responsible for the whole finger actuation and in an open position, fingers can get into gimbal lock and making fingers in slightly bent position fixes this issue.

Group 1 fingers are the thumb and index finger. They can fold and unfold as group 2 fingers, and they are structured the same way as group 2 fingers. However, the part between the finger and connection module, which is shown in *Figure 11 (e)*, differs from the group 1 finger's connection part. The part has two bearings on its top and bottom, which enable movement to the sides with the help of connected strings. The connection part of the strings is shown in *Figure 12 (a)*, and the parts that are being attached to the bearing are shown in *Figure 12 (b)*. These are the connections that are needed to add one more degree of freedom. Additional degrees of freedom are added to all group 1 fingers by the same technique.

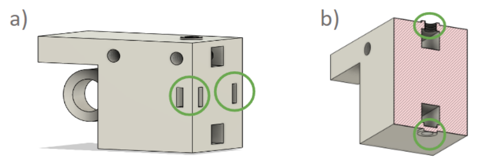


Figure *12*. Connection part between connection module to the palm and index finger; a) Strings attachment points; b) Attachment points to the bearings.

For assembling SemuBot's parts, assemblies and models are provided in the GitHub repository that I have created, as shown in *Appendix 4*.

6.2 SemuBot's Hand Movement Mechanism

First prototype of SemuBot's hand works with a tendon-driven mechanism.

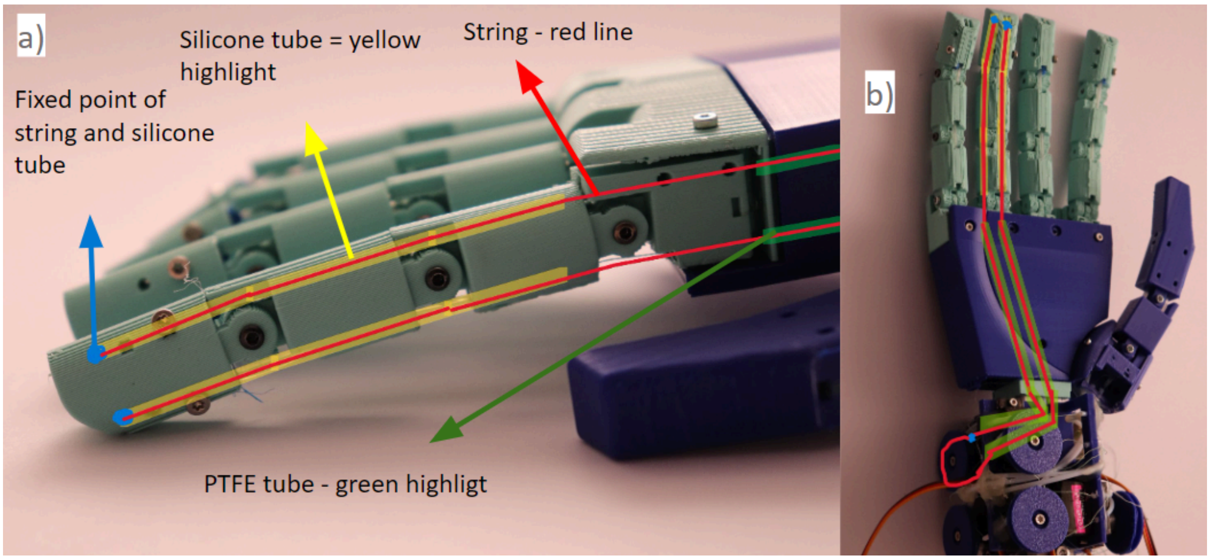


Figure 13. Semubot's hand's string and tube connections.

In *Figure 13(a)*, strings and silicone tubes are connected to the tips of the fingers from the bottom and top. The strings pass through the silicone tubes. At the connection point between the fingers and the palm and also at the motor's shell, PTFE tubes are glued, as shown in *Figure 14 ((a) and Figure 14 (b))*. This allows strings that are attached to the fingers to reach the motors for actuation. The string runs through the PTFE tube and connects to the same point on the motor's wheel, creating a belt-like mechanism. When the string connected to the lower part of the fingertip is pulled, the finger folds; when the string connected to the upper part of the fingertip is pulled, the finger unfolds. In the same way, by pulling strings, it is possible to move group 2 fingers sideways and give them one more degree of freedom.

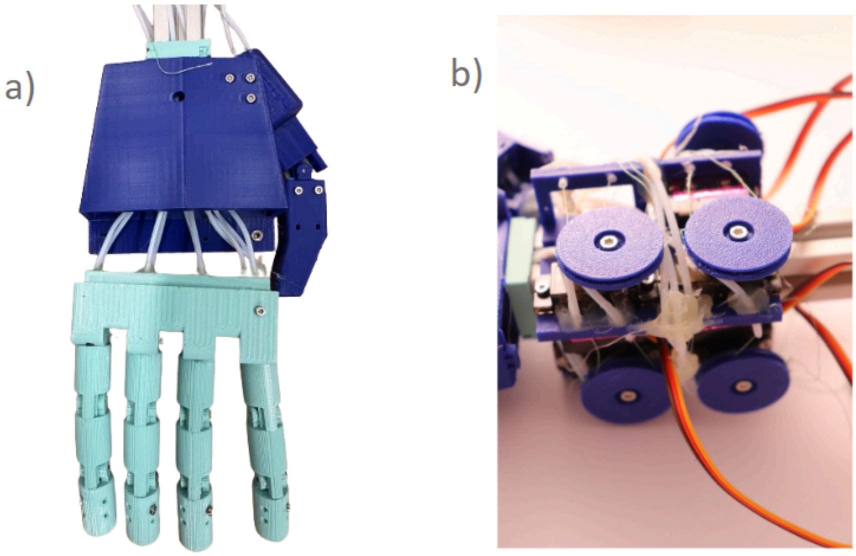


Figure 14. a) Pathway of PTFE tubes; b) Attachment points of PTFE tubes on the motor side.

Arduino Nano is used to actuate servo motors. In *Appendix 5*, the code block for Arduino nano and Python file for actuating fingers is given. In the Python environment serial and time libraries are used.

6.3 Bill of Materials

In Table *4,* you can see the list of materials that are used and their cost if applicable. PLA is used for printing materials. Its printing temperature is 230 degrees Celsius. It is a preferable material as it is easy to print. ASA has been used for the parts that require high durability and stability. This material is preferred because screws do not damage it but rather secure the components firmly in place. Servo motors with metal gear have been chosen as they are cheap, reliable, easy to integrate and available. M2 size has been preferred for screws and bearings in general, as it is the proper size to create joints for the current version of the hand. M5-size screws are used to keep the motors' shells fixed in place, and M6-size screws are used to connect the palm section to the extrusion. Arduino Nano is used to connect and actuate motors. Silicone tubes are utilised to prevent strings from becoming trapped between the joints. These tubes also offer excellent flexibility, allowing them to bend easily and accommodate the hand's movements. PTFE tubes are used to guide the strings from the fingers to the motors. PTFE tubes can be glued (with a hot glue), ensuring they stay securely fixed in place. Bearing is one of the materials that is used. They are important in the current hand design for creating proper bending/unbending joints.

Row	**Material**	**Amount**	**Price**
1	PLA	148.26 grams (without supports)	4 euros
2	Servo motors with motor gears (MG90S)	7	18.2 euros
3	M2 bearing	18	-

4	M2 screw	19	-
5	M2.5 screw	7	-
6	M5 screw	2	-
7	M6 screw	1	-
8	Arduino Nano	1	25 euros
9	PTFE tube	2 m	5 euros
10	Silicone tube	2 m	7.5 euros
11	Bearings	19	15 euros
12	3D printing	-	10 euros
13	Assembling	Upmost 2 hours	-
14	ASA	2 g	-

Table 4. Materials that have been used for SemuBot's hand.

6.4 Compliance of SemuBot's Hand with Initial Requirements

SemuBot's hand requirements are shown in *Table 2*. The underlying requirements are met in this work.

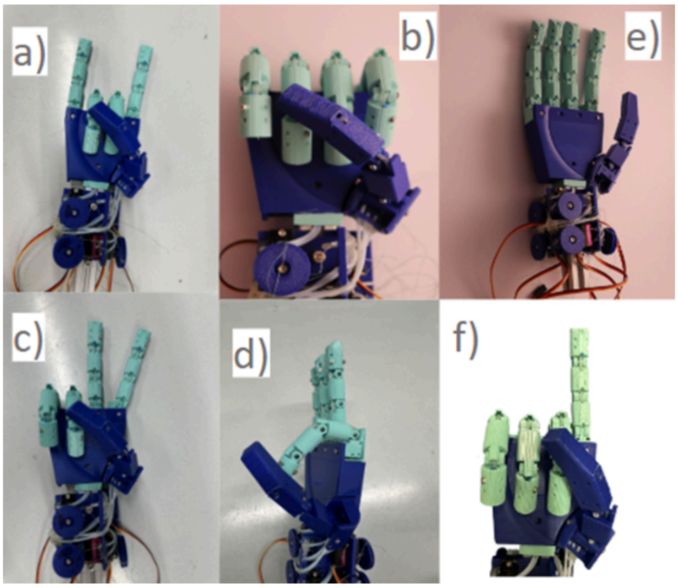


Figure 15. SemuBot's hand illustrating hand gestures

SemuBot's hand needs to be able to show hand gestures(*Figure 3*). Some of the hand gestures done by SemuBot's hand are shown in *Figure 15*. Being able to show hand gestures, SemuBot can interact with patients. Furthermore, showing hand signs also enables SemuBot to play games like rock, paper, and scissors. Rock, paper and scissors would correspond to *Figure 15 (b)*, *Figure 15 (e)* and *Figure 15 (c)*.

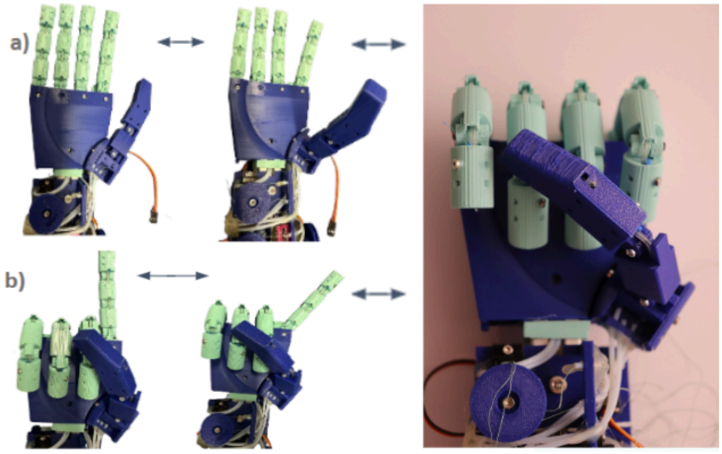


Figure 16. a) SemuBot’s hand thumb 2 degrees of movement; b) SemuBot’s hand index finger 2 degrees of movement.

Showing hand gestures is possible thanks to the index finger and thumb, which has 2 degrees of freedom. In *Figure 16*, 2 degrees of freedom on the index finger and thumb can be seen.

SemuBot’s hand, according to the requirements, has to be less than a kilo, and it is 351 grams (*figure 17*), which meets the requirements well. This lightweight design ensures ease of movement and efficiency.

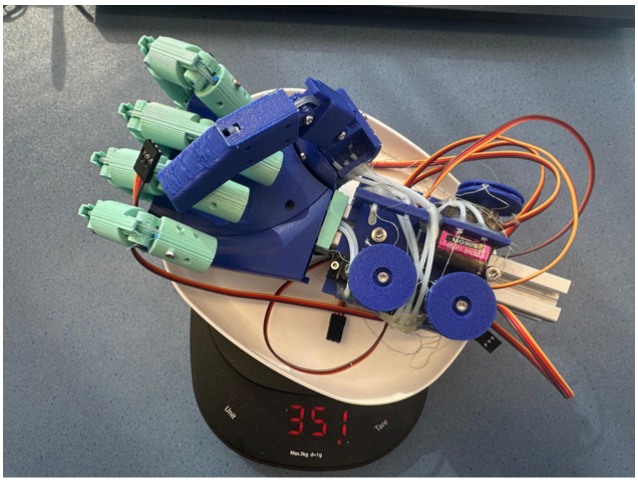


Figure 17. Weight of SemuBot’s hand.

As shown in *Figure 8*, SemuBot’s hand parts are separated in the first prototype. Separate parts are necessary for this work to be modular. Fingers and motors can be replaced, which makes the robotic hand modular. Being able to have robotic fingers in different sizes makes them customisable. The comparison of size of the thumb and other fingers is a good example. For example, in *Figure 10 (e)* and *Figure 10 (d)*, index finger and thumb assemblies can be shown accordingly. They have the same mechanism, but their dimensions and shapes are different.

The total cost of the materials used for the prototype is approximately 85 euros, meeting the requirement of being under 500 euros. The detailed cost breakdown is provided in *Table 4*.

SemuBot's hand is open-source; when some parts are broken, they can easily be downloaded from the GitHub repository provided in *Appendix 5*. After downloading it as a mesh file, it can be sliced and 3D printed.

In *Table 5,* SemuBot's compliance with initial requirements is shown, and most of the requirements are met. Only noise level and proportionality need to be improved.

Row	**Requirement**	**If a requirement is met by first prototype of SemuBot's hand(Yes/No)**
1	Hand gestures	Yes
2	Degrees of Freedom - index finger and thumb should have more than 2 degrees of freedom	Yes
3	Weight under 1 kilo	Yes
4	Open-source	Yes
5	Modularity	Yes
6	Forearm size should be less than 8 cm	Yes
7	The price must be less than 500 euros	Yes
8	The noise level must be less than 30dB	No
9	Proportionality	No

Table 5. Compliance of SemuBot's hand with initial requirements.

6.4 Comparison of SemuBot's Hand to Other Robotic Hands

In *Table 6, a* comparison of the first prototype of SemuBot's hand to other robotic hand applications is shown. Comparison is made according to SemuBot's hand requirements. We can see that the current prototype is filling most of the requirements.

Row	**Existing prototypes**	**Mechanism**	**Open-source**	**Low Price(Under 500 euros)**	**Sound level under 30dB**	**At least 2 degrees of freedom on index finger and thumb**	**Weight (kg)**	**Modular**

1	DexHand[28]	Tendon-driven mechanism	Yes	Yes	No	Yes	1.4 kg	Yes
2	ILDA hand[31]	Linkage-drive mechanism	No	No information	No information	Yes	1.1 kg	No
3	Shadow hand[29]	Tendon-driven mechanism	No	No	No information	Yes	4.3 kg	Yes
4	Hydraulic circuit actuated robotic hand[32]	Hydraulic circuit actuation mechanism	No	Yes	No	No	3.3 kg	No
5	SemuBot's hand first prototype	Tendon-driven mechanism	Yes	Yes	No	Yes	0.351 kg	Yes

Table 6. Comparison of different robotic hands to the first prototype of SemuBot's hand.

SemuBot's hand's first prototype was made. First prototype meets most of the requirements, including making hand gestures, which is crucial in this work. SemuBot's hand's robotic fingers have 3 degrees of freedom on each finger in group 1 and 4 degrees of freedom on group 2 fingers. In total, the fingers have 17 degrees of freedom(*Table 7*) and seven actuators(*Table 4, Row 2*).

Row	Finger	Total DoF	Independent DoF	Dependent DoF	Motors needed for actuation
1	Little finger	3	1	2	1
2	Ring finger	3	1	2	1
3	Middle finger	3	1	2	1
4	Index finger	4	2	2	2
5	Thumb	4	2	2	2

Table 7. Degrees of freedom of fingers of SemuBot's hand.

Conclusion

The introduction of the SemuBot hand is an important towards enhancing the socialisation skills of children by enabling SemuBot to interact with gestures. The first prototype of the SemuBot hand demonstrates a viable solution to most of the requirements that are given for SemuBot's hand while also providing a good platform for future iterations of said hand. A bioinspired tendon-driven mechanism makes the hand relatively lightweight. SemuBot's hand is modular and open-source, which is very important for sustainability as being open-source and modular makes the hand more repairable. Here are the main developments of the designed hand:

Seven degrees of freedom ensures the SemuBot's hand is able to show multiple gestures that are vital for SemuBot to have human-like body language and social interactions. Modularity enables rapid prototyping due to the replaceable parts. SemuBot's hand is relatively affordable: the price of the prototype is well under 500 euros - 84.7 euros, which would allow further democratisation of its utilisation. Low level of noise: the current servo motors are still more noisy than the 30 dB level, but future versions will be less noisy for the user's comfort. These achievements not only make the hand a useful tool for assisting the child in socialising, but also make it available for further research and improvement as motors and fingers are customisable. In general, the SemuBot hand demonstrates the integration of open-source, modularity, and cost-reduction solutions in education or recovery therapy. Further work and testing are needed for SemuBot to become an effective tool for improving children's social skills.

Future Work

In the first prototype of SemuBot, the sound level is more than 30dB, and it does not meet the sound requirements. The motor's connection part is modular, and it can be replaced. Motors like voice coil motors, which do not have sound or a low level of sound, must be chosen.

According to the requirements, a more proportional version of the hand needs to be made. SemuBot's height is 150 cm. Artistic vision must be integrated, and the hand must look proportional when inserted into the robot.

Acknowledgements

First and foremost, I express my deepest gratitude to my supervisors, Professor Dr Alvo Aabloo and Leonid Zinatullin, for guiding me and supporting me while working on various aspects of this research and providing constructive advice at each stage. Their knowledge of the subject and motivation were key to the completion of this thesis. Equally, I am grateful to the Institute of Technology of the University of Tartu for providing me with the resources, facilities, and information needed to undertake this research. Additionally, I want to offer my special thanks to the administrative staff, who have only been helpful and accommodating during the process of conducting the research. I would also like to thank the rest of the group members of the IMS lab. Together, we have collaborated, shared insights, given advice, and provided feedback. They have made this research experience even more rewarding. My sincere thanks also go to my family and friends for their continuous support and their encouragement that kept me driven to achieve my very best. Finally, I am grateful to the pool of researchers and practitioners whose work has laid the foundation and inspiration for my study. It is through reading and learning about their studies that I have been able to carry out my studies. Thank you all once again for your support and contribution towards the achievement of this thesis.

References

[1] Raver, C. C., Blackburn, E. K., Bancroft, M., & Torp, N. (2000). Relations between effective emotional regulation, emotional expressiveness, and representations of relationships in preschool children. Developmental Psychology, 36(6), 711-722. https://doi.org/10.1037/0012-1649.36.6.711

[2] Stancheva-Popkostadinova, V., Dimitrov, G., Rasheva-Yordanova, K., & Kostadinova, I. (2023). Exploring the Potential of Social Robots for Speech and Language Therapy: A Review and Analysis of Interactive Scenarios. Machines, 11(7), 693. https://doi.org/10.3390/machines11070693

[3] EnableMe. (14.04.2024). Der Mensch als soziales Wesen. Retrieved 14.04.2024, from https://shorturl.at/033LZ

[4] Gjedia, R., & Gardinier, M. P. (2018). Mentoring and teachers' professional development in Albania. European Journal of Social Sciences Education and Research, 5(1), 331-336. https://doi.org/10.26417/ejser.v5i1.p331-336

[5] Johnson AM, Hawes DJ, Eisenberg N, Kohlhoff J, Dudeney J. Emotion socialization and child conduct problems: A comprehensive review and meta-analysis. Clin Psychol Rev. 2017 Jun;54:65-80. doi: 10.1016/j.cpr.2017.04.001. Epub 2017 Apr 8. PMID: 28414957. https://pubmed.ncbi.nlm.nih.gov/28414957/

[6] SoftBank Robotics. n.d. Pepper Robot. Image. Accessed May 24, 2024. https://www.aldebaran.com/themes/custom/softbank/images/full-pepper.png.webp

[7] Kolk, A. et al., "Structured Model of Neurorehab", Applied Neuropsychology: Child, DOI: 10.1080/21622965.2018.1486193.

[8] Kolk, A. et al., "Power of combined modern technology", Applied Neuropsychology: Child, DOI: 10.1080/21622965.2022.2066532.

[9] Ulhøi, J., & Nørskov, S. (2022). The emergence of social robots: Adding physicality and agency to technology. Journal of Engineering and Technology Management, 65, 101703. https://doi.org/10.1016/j.jengtecman.2022.101703]

[10] Ashraf, H. (2023). Humanoid Robots-Recent Developments & Human-Robot Interaction: A paper review. ResearchGate. https://doi.org/10.13140/RG.2.2.19016.80641

[11] Pollen Robotics. (05.19.2024). Reachy. Retrieved from https://www.pollen-robotics.com/reachy/

[12] PAL Robotics. (05.19.2024). TIAGo Mobile Manipulator Robot. Image. Retrieved from https://pal-robotics.com/wp-content/uploads/2024/04/TIAGo-Mobile-Manipulator-Robot-600x669.webp

[13] PAL Robotics. (20.05.2024). REEM-C Robot [Image]. Retrieved from https://pal-robotics.com/wp-content/uploads/2024/04/REE-C-Robot-3-918x1024.webp

[14]SoftBank Robotics. (n.d.). Pepper Robot. [Image]. Retrieved May 24, 2024, from https://www.aldebaran.com/themes/custom/softbank/images/full-pepper.png.webp

[15] AI for Good. (11.04.2024). Sophia. Retrieved from https://aiforgood.itu.int/speaker/sophia/

[16] Movia Misty Kid. (05.19.2024). Image. Retrieved from https://static.wixstatic.com/media/7413c6_5b8566734eea43378b8e68a27ff2ee42~mv2.jpg/v1/crop/x_184,y_0,w_656,h_768/fill/w_415,h_495,al_c,q_80,usm_0.66_1.00_0.01,enc_auto/movia-misty-kid_edited.jpg

[17] Promobot. (11.04.2024). Image. Retrieved from https://promo-bot.ai/wp-content/uploads/2020/02/GX3A8395.jpg

[18] SoftBank Robotics. (11.04.2024). NAO. Image. Retrieved from https://us.softbankrobotics.com/hs-fs/hubfs/SBR_NAO-photo-03.jpg?width=755&height=989&name=SBR_NAO-photo-03.jpg

[19] PAL Robotics. (19.05.2024). TIAGo Mobile Manipulator Robot. Retrieved from https://pal-robotics.com/robots/tiago/

[20] PAL Robotics. (11.04.2024). REEM-C. Retrieved from https://pal-robotics.com/robots/reem-c/

[21] SoftBank Robotics. (11.04.2024). Pepper: Humanoid and programmable robots for businesses and education. Retrieved from https://us.softbankrobotics.com/pepper

[23] Movia Robotics. (19.05.2024). Misty. Retrieved from https://www.moviarobotics.com/misty

[24] Promobot. (11.04.2024). Medical Assessor. Retrieved from https://promo-bot.ai/use-case/medical-assessor/

[25] RobotLAB. (11.04.2024). NAO Power V6 Standard Edition. Retrieved from https://www.robotlab.com/higher-ed-robots/store/nao-power-v6-standard-edition

[26] SoftBank Robotics. (11.04.2024). NAO. Retrieved from https://www.softbankrobotics.com/emea/en/nao

[27] Bonvoisin, J., Mies, R., Boujut, J.-F., & Stark, R. (2017). What is the “Source” of Open Source Hardware?. Journal of Open Hardware, 1(1). DOI: https://doi.org/10.5334/joh.7

[28] The Robot Studio. (17.11.2023). DexHand. Retrieved 11.04.2024, from https://www.dexhand.org/

[29] Robots Guide. (11.04.2024). Shadow. Retrieved from https://robotsguide.com/robots/shadow

[30] Shadow Hand. (11.04.2024). Image. Retrieved form https://cdn.sanity.io/images/7p2whiua/production/f6286052109fbc847c2daa4f12a8d3ee37ca238f-2048x1536.jpg?w=1400&auto=format

[31] Cao, W., Yan, Y., Wu, C., ... & Zhou, W. (2021). Nature Communications. Article Title. Retrieved from https://www.nature.com/articles/s41467-021-27261-0

[32] Kang, T., Kaminaga, H., & Nakamura, Y. (n.d.). A Robot Hand Driven by Hydraulic Cluster Actuators. Retrieved from https://www.cs.cmu.edu/~cga/exo/eh/hand-cluster.pdf

Appendices

Appendix 1

SemuBot’s general requirements

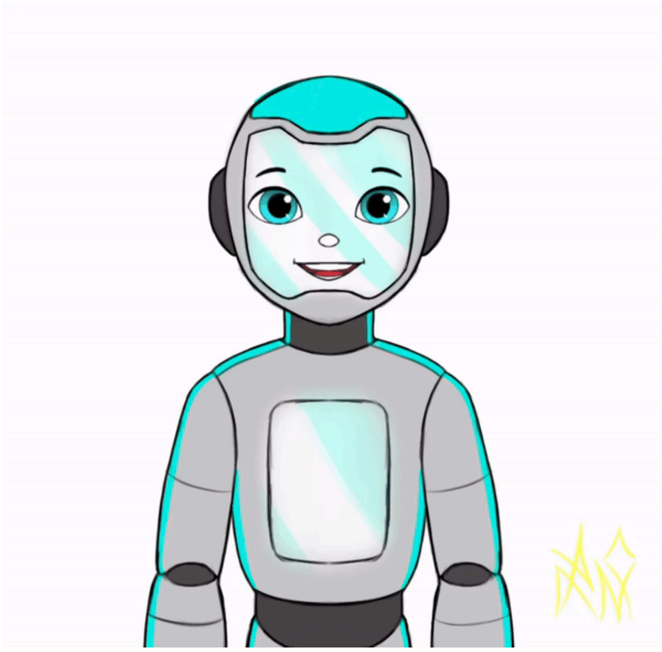
requirements document 2April2023.docx

Appendix 2

SemuBot’s system requirements

System requirements

Appendix 3



SemuBot’s illustration gif

Appendix 4

Dexhand gif

Appendix 5

Github Repository of SemuBot's hand: https://github.com/Mikelangelo007/SemuBot-s-hand-/

Appendix 6

The C++ code block for Arduino Nano:

```
#include <Servo.h>

Servo myservo1;
Servo myservo2;
Servo myservo3;
Servo myservo4;
Servo myservo5;
Servo myservo6;
Servo myservo7;

void setup() {
  Serial.begin(9600);
  myservo1.attach(A2);  // First servo on pin A2
  myservo2.attach(A3);  // Second servo on pin A3
  myservo3.attach(A0);  // Third servo on pin A0
  myservo4.attach(A1);  // Fourth servo on pin A1
  myservo5.attach(A4);  // Fifth servo on pin A4
  myservo6.attach(A5);  // Sixth servo on pin A5
  myservo7.attach(A7);  // Seventh servo on pin A6
}

// Define functions for each servo
void set_servo1_angle(int angle) {
  myservo1.write(angle);
  Serial.println("First servo angle set to: " + String(angle));
}

void set_servo2_angle(int angle) {
  myservo2.write(angle);
  Serial.println("Second servo angle set to: " + String(angle));
}

void set_servo3_angle(int angle) {
  myservo3.write(angle);
  Serial.println("Third servo angle set to: " + String(angle));
}
```

```
void set_servo4_angle(int angle) {
  myservo4.write(angle);
  Serial.println("Fourth servo angle set to: " + String(angle));
}

void set_servo5_angle(int angle) {
  myservo5.write(angle);
  Serial.println("Fifth servo angle set to: " + String(angle));
}

void set_servo6_angle(int angle) {
  myservo6.write(angle);
  Serial.println("Sixth servo angle set to: " + String(angle));
}

void set_servo7_angle(int angle) {
  myservo7.write(angle);
  Serial.println("Seventh servo angle set to: " + String(angle));
}

void loop() {
  if (Serial.available() > 0) {
    char command = Serial.read();
    switch(command) {
      case 'a':
        set_servo1_angle(Serial.parseInt());
        break;
      case 'b':
        set_servo2_angle(Serial.parseInt());
        break;
      case 'c':
        set_servo3_angle(Serial.parseInt());
        break;
      case 'd':
        set_servo4_angle(Serial.parseInt());
        break;
      case 'e':
        set_servo5_angle(Serial.parseInt());
        break;
      case 'f':
        set_servo6_angle(Serial.parseInt());
        break;
      case 'g':
        set_servo7_angle(Serial.parseInt());
        break;
```

```
    }
  }
}
```

Python code block for actuation of motors:

```
import serial
import time

arduino_port = 'COM5'  # Adjust as necessary
baud_rate = 9600

try:
    ser = serial.Serial(arduino_port, baud_rate, timeout=1)
except serial.SerialException as e:
    print("Error opening serial port:", e)
    exit()

def set_servo_angle(servo_id, angle):
    command = f'{servo_id}{angle}\n'
    ser.write(command.encode('utf-8'))
    time.sleep(0.1)  # Delay for servo movement
try:
    while True:

        set_servo_angle('b', 180) # Ring finger close
        time.sleep(2)
        set_servo_angle('b', 0) # Ring finger open
        time.sleep(2)
        # set_servo_angle('a', 0) # index finger close
        # time.sleep(0.8)
        # set_servo_angle('f', 10) # index finger right
        # time.sleep(0.8)
        # set_servo_angle('a', 180) # index finger open
        # time.sleep(0.8)
        # set_servo_angle('c', 180) # Little finger close
        # time.sleep(2)
        # set_servo_angle('c', 0) # Little finger open
        # time.sleep(2)
        # set_servo_angle('d', 180) # Thumb close
        # time.sleep(2)
        # set_servo_angle('d', 0)  # Thumb open
        # time.sleep(2)
        # set_servo_angle('e', 180) # Middle finger close
        # time.sleep(2)
```

```
        # set_servo_angle('e', 0) # Middle finger open
        # time.sleep(2)


        # set_servo_angle('f', 30) #index finger middle
        # time.sleep(0.8)

        # set_servo_angle('g', 0) # Thumb right
        # time.sleep(2)
        # set_servo_angle('g', 180) # Thumb left
        # time.sleep(2)
except KeyboardInterrupt:
    print("Program terminated by user.")
finally:
    ser.close()
```

Non-exclusive licence to reproduce the thesis and make the thesis public

I, Elchin Huseynov

1. grant the University of Tartu a free permit (non-exclusive licence) to

reproduce, for the purpose of preservation, including for adding to the DSpace digital archives until the expiry of the term of copyright, my thesis

Design and Control of Social Humanoid Robot's - SemuBot's Hand

supervised by Prof., PhD Alvo Aabloo and Leonid Zinatullin

2. I grant the University of Tartu a permit to make the thesis specified in point 1 available to the public via the web environment of the University of Tartu, including via the DSpace digital archives, under the Creative Commons licence CC BY NC ND 4.0, which allows, by giving appropriate credit to the author, to reproduce, distribute the work and communicate it to the public, and prohibits the creation of derivative works and any commercial use of the work until the expiry of the term of copyright.

3. I am aware of the fact that the author retains the rights specified in points 1 and 2.

4. I confirm that granting the non-exclusive licence does not infringe other persons' intellectual property rights or rights arising from the personal data protection legislation.

Elchin Huseynov

21/05/2024