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Flexible Screen Integration and Development of Neck Movement Mechanism for Social Humanoid Robot SemuBot

Bachelor's Thesis (12 ECTS)

Curriculum Science & Technology

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Finding and Implementing the Solution for the Face of the Humanoid Robot; Developing a Neck Mechanism for the Humanoid Robot

Abstract

Effective communication and interaction are pivotal for integrating humanoid robots into human-centric environments. Central to the functionality of a social humanoid robot is its ability to engage with humans through facial expressions and neck movement gestures.

This thesis focuses on the critical task of designing and implementing solutions for the face of a humanoid robot and developing a corresponding neck mechanism to enhance the communicative abilities of humanoid robots.

The research entails designing, experimenting, and integrating a work solution for a humanoid robot's face and neck mechanism of a social humanoid robot, SemuBot. The project uses computer-aided design modelling and 3D printing. The implementation involves utilising specialised hardware such as flexible screens, stepper motors for neck actuation, and microcontrollers for seamless integration and control. Additionally, the development process involves iterative design, testing, and integration of the flexible screen and neck mechanism. This work culminates in presenting a functional prototype, demonstrating the proposed facial and neck mechanism solutions' efficacy in enhancing the robot's social interaction capabilities and overall human-like appearance.

Keywords

Humanoid robot, Social robot, AI (Artificial Intelligence), HMI (Human-Machine Interface), CAD (Computer-Aided Design), 3D printing, Flexible screens, Stepper motors, Neck mechanism, Robot-human interaction, Rehabilitation robotics, Open-source robotics, Mechanical engineering, Robotics in therapy, SemuBot, OLED, AMOLED, LCD

CERCS: T125 Automation, robotics, control engineering; T170 Electronics; T210 Mechanical engineering, hydraulics, vacuum technology, vibration acoustic engineering

Humanoidroboti näo lahenduse leidmine ja rakendamine; humanoidroboti jaoks kaela mehhanismi väljatöötamine

Lühikokkuvõte

Tõhus suhtlus on humanoidrobotite inimkesksesse keskkonda integreerimisel kesksel kohal. Sotsiaalse humanoidroboti funktsionaalsuse keskmes on selle võime suhelda inimestega näoilmete ja kaela liikumise žestide kaudu.

Antud lõputöö keskendub humanoidroboti näo lahenduste kavandamise ja rakendamise kriitilisele ülesandele ning vastava kaelamehhanismi väljatöötamisele humanoidrobotite kommunikatiivsete võimete suurendamiseks.

Lõputöö hõlmab sotsiaalse humanoidroboti semuboti humanoidroboti näo-ja kaelamehhanismi tervikliku lahenduse kavandamist, katsetamist ja juurutamist. Projekt kasutab arvutipõhist disaini modelleerimist ja 3D-printimist. Rakendamine hõlmab spetsiaalse riistvara kasutamist, näiteks painduvad ekraanid, samm-mootorid kaela käivitamiseks ja mikrokontrollerid sujuvaks integreerimiseks ja juhtimiseks. Lisaks hõlmab arendusprotsess paindliku ekraani ja kaela mehhanismi iteratiivset kujundamist, testimist ja integreerimist. See töö kulmineerub funktsionaalse prototüübi esitlemisega, demonstreerides pakutud näo - ja kaelamehhanismi lahenduste tõhusust roboti sotsiaalse suhtluse võimete ja üldise inimesesarnase välimuse parandamisel.

Võtmesõnad:

Humanoidrobot, sotsiaalne robot, AI (Tehisintellekt), HMI (inimese ja masina liides), CAD (arvutipõhine disain), 3D-printimine, painduvad ekraanid, samm-mootorid, Kaelamehhanism, roboti ja inimese suhtlus, Rehabilitatsioonirobootika, avatud lähtekoodiga Robootika, Masinaehitus, Robootika teraapias, SemuBot, OLED, AMOLED, LCD

CERCS: T125 Automatiseerimine, robootika, juhtimistehnika; T170 Elektroonika; T210 Masinaehitus, hüdraulika, vaakumtehnoloogia, vibratsioonakustiline tehnoloogia

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TERMS, ABBREVIATIONS AND NOTATIONS

- **AI**: Artificial Intelligence
- **AMOLED**: Active Matrix Organic Light Emitting Diode
- **CAD**: Computer-Aided Design
- **CERCS**: Common European Research Classification Scheme
- **DOF**: Degree of Freedom
- **HMI**: Human-Machine Interface
- **LCD**: Liquid Crystal Display
- **LED**: Light-Emitting Diode
- **OLED**: Organic Light Emitting Diode
- **TFT**: Thin-film transistor
- **V1**: Version 1

1 INTRODUCTION

It has not been long since the impact of robotics technology has significantly increased. Robotics has revolutionised our world, starting from agriculture [1] to the healthcare industry [2]. Nowadays, robots have even become integral parts of our own houses [3]. Among all the forms of various robots, one type of robot has prevailed the most. Social robots have recently begun to be developed by many companies, and even more, these robots have started to integrate into our social infrastructure. Social robots are already providing help for people in shopping malls [4] and even assist older adults and those with dementia [2]. Of course, it goes without saying that the most essential aspect of a social humanoid robot is communication.

One cannot overestimate the role of face and facial expressions in communication and interaction with humans [5]. Additionally, neck motion is crucial in helping people communicate [6]. Therefore, creating a face capable of showing a wide range of emotions and a neck that supports facial expressions with gestures is essential.

The thesis aims to develop a face and neck mechanism for the humanoid social robot companion SemuBot that is intended for communication training in the therapy of children with special needs. The expected head consists of 3D-printed plastic parts serving as a head, a flexible screen as a face, a stepper motor for the neck actuation, 3D-printed plastic models for head connection and neck actuation, a bearing, aluminum extrusions serving as a spine of the robot and support constructions inside the head of the robot.

2 LITERATURE REVIEW

2.1 Social robotics

Social robotics is emerging as a significant area of research, closely linked with advancements in various technologies. Social robots are increasingly utilised in domestic spaces, educational and industrial environments, and, of course, commercial enterprises [7]. These robots' interactive and dynamic capabilities, coupled with their proficiency in hearing, understanding, and responding to human speech and emotions, render them well-suited for social application domains [8].

Social robots are designed to engage with humans in a way that mimics natural social interactions, which include using gestures, facial expressions, and body language to communicate effectively [9]. This makes them particularly valuable in settings such as elder care, where they can provide companionship and assist with daily tasks, thus improving the quality of life for seniors [2]. In educational contexts, social robots can serve as tutors or teaching assistants, offering personalised learning experiences and supporting students with special needs [10].

Social robots are employed in customer service roles in the commercial sector, providing information and assistance in retail stores, hotels, and banks [4]. Their ability to interact naturally with customers can enhance the user experience and increase customer satisfaction. Additionally, in industrial settings, social robots can work alongside human workers, improving productivity and safety by taking on repetitive or hazardous tasks [11].

Integrating social robots into various aspects of daily life is facilitated by ongoing research in natural language processing, computer vision, and machine learning [12]. These technologies enable robots to understand better and predict human behaviour, allowing for more seamless and intuitive interactions. Moreover, ethical considerations and social implications of deploying such robots are being studied to ensure that their integration into society is beneficial and aligns with human values [13].

As social robots continue to evolve, they hold the potential to transform how we interact with technology and each other, fostering a more connected and empathetic society.

2.2 Social Robots

Nowadays, a considerable number of official companies and just enthusiastic people are passionate about developing social robots. The market has a lot of social robots to choose from, and each is designed to meet a specific need. Even though social robots still share some similar features and functions.

There are numerous examples of social robots. One of them is a social robot, Kismet (Fig. 1), made by the Massachusetts Institute of Technology (MIT) [14], one of the first robots to demonstrate social and emotional interactions with humans. It had a cartoonish face and spoke with a squeaky baby voice. For Kismet to appropriately interact with human beings, it contains input devices that give it auditory, visual, and proprioception abilities. Kismet simulates emotion through various facial expressions, vocalisations, and movement. Facial expressions are created through ears, eyebrows, eyelids, lips, jaw, and head movements.

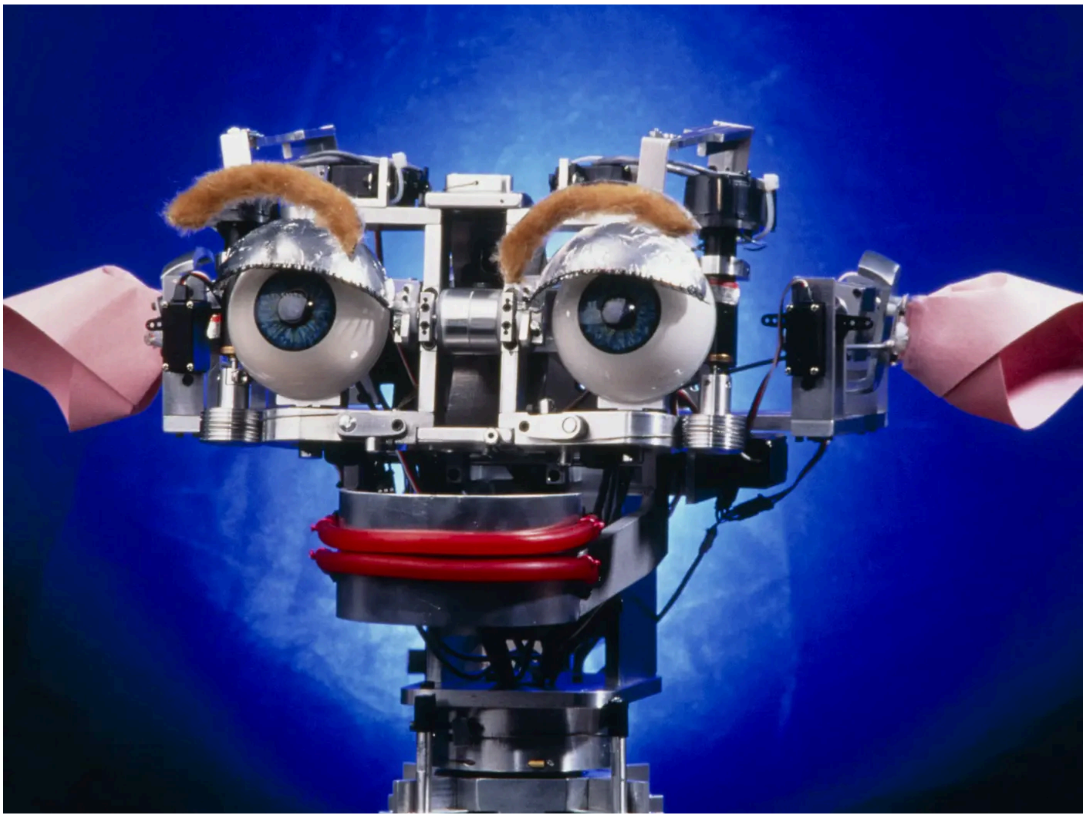


Fig. 1. *Kismet, the first social robot [15].*

Despite its high cost, Kismet played an essential role in social robotics and became one of the founders in this field, as it appeared to be a very successful example of a social robot.

One another example of a social robot is Misty II by Misty Robotics [16] (Fig. 2). It is a personal robot designed specifically for people interested in programming and robotics. The robot features a 4K camera for image recognition, three microphones, an Occipital 3D depth sensor with dual IR cameras to help with three-dimensional room mapping, an LCD for expressing emotions and six capacitive touch panels around a head, which boasts three degrees of movement freedom [16].

Fig. 2. *Misty II, a personal robot [16].*

2.3 Humanoid Robots

Although Misty and Kismet are social, they are not considered humanoid robots. Humanoid robots are robots whose design exhibits more anthropomorphic characteristics. These robots are specifically crafted to resemble human beings, often mirroring our physical features and movements, thus mimicking human appearance and functionality [17]. There are different types of humanoid robots, but the two most common types are social humanoid robots and humanoid robots, designed to push the human body's limits.

One of the well-known examples of robots that push the human body’s limits is Atlas, made by Boston Dynamics [18] (Fig. 3). This robot represents a significant advancement in humanoid robotics, designed to mimic human form and function with high precision and capability. Initially, Atlas featured a hydraulic system, but recent iterations have transitioned to a fully electric model, emphasising enhanced performance and real-world applicability.

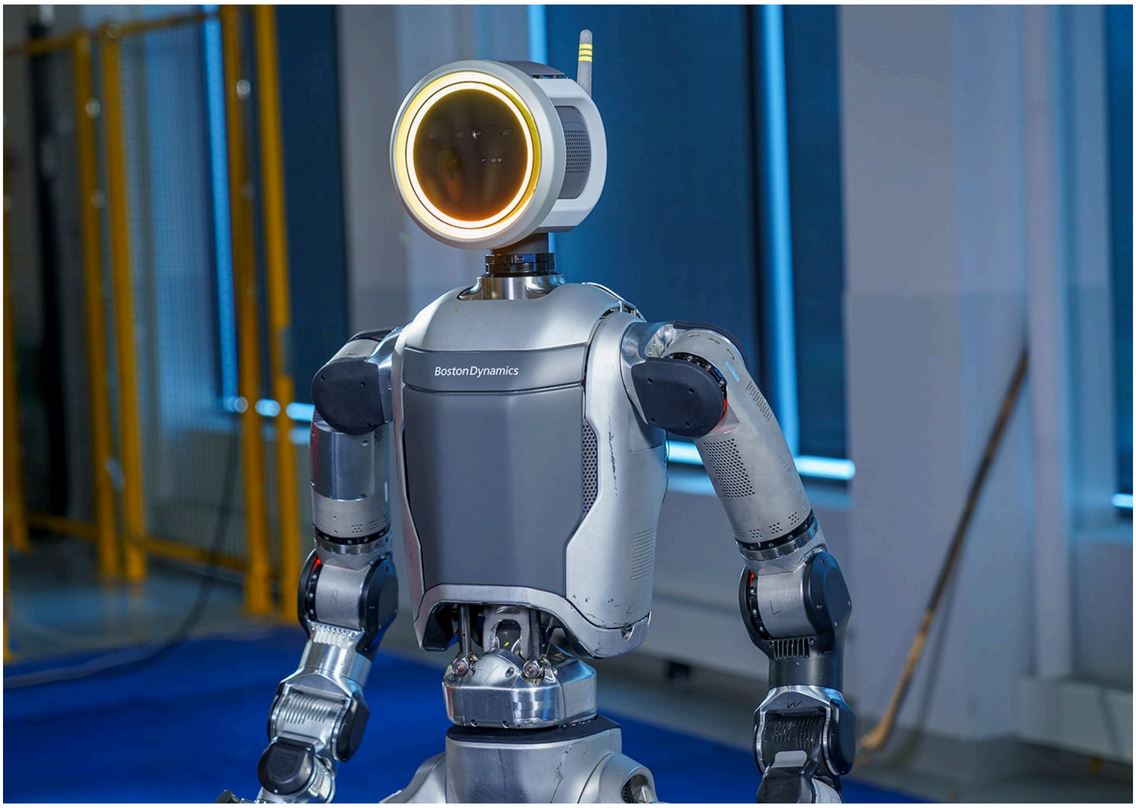


Fig. 3. *Atlas, a humanoid robot [18].*

The primary goal of Atlas is to address some of the toughest challenges in various industries by performing tasks that are dull, dirty, or dangerous for humans by pushing its human-like body to its limits.

As mentioned above, humanoid robots also often have the purpose of being social robots. The intentional mimicry of human appearance and behaviour aims to facilitate more natural and intuitive interactions between robots and humans. One of the well-known examples of humanoid social robots is a Pepper robot by SoftBank Robotics [19] (Fig. 4). This 1.2-meter tall robot features 17 joints for expressive body language, omnidirectional wheels for smooth movement, and advanced capabilities for perceiving and interacting with humans. Pepper is designed to be non-threatening and approachable, avoiding the "uncanny valley" with a gender-neutral appearance. Pepper was initially developed to assist staff and engage customers in SoftBank stores, showcasing the potential of robots in customer service roles. However, its applications have expanded significantly, and now it is used in educational and domestic use as well as public service and healthcare.

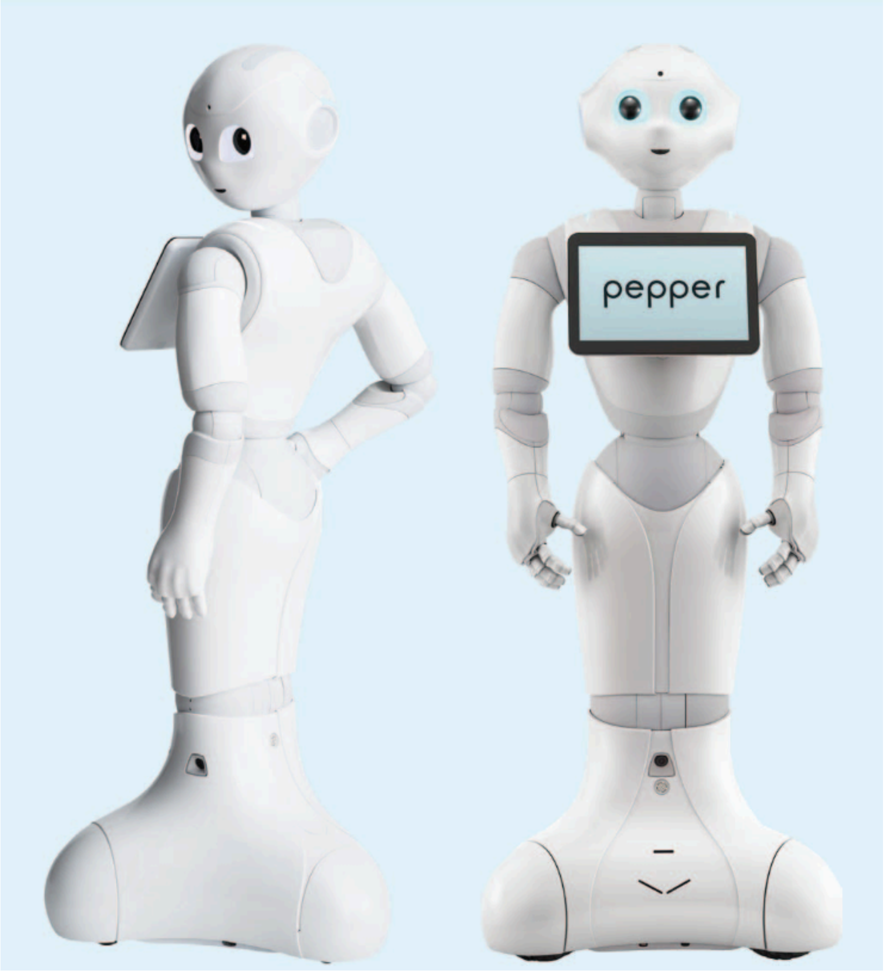


Fig. 4. *Pepper, a social humanoid robot [19].*

2.4 Open-Source Robots

Unfortunately, many modern robots are closed-source. This is true for both the robot's hardware and software. Companies often prefer to keep the robot's hardware and software secret from users. Even though it benefits companies, it is only sometimes helpful for robot users. Open source is essential for the best user experience. Open source means that the data about the hardware and software is available to everyone who needs it. It allows the users to modify the product in the way they want. Besides, it is very beneficial in educational terms [43] [44]. Inquisitive users can disassemble the robot, learn how it was made, and upgrade the pieces the robot is made of. It also allows them to dive into the programming part of the robot and adjust the code to the user's particular needs. Moreover, if the robot breaks, a user can replace any parts without needing to buy expensive parts of the robot separately or send the product back to the company for fixing.

There are several examples of open-source robots. The most famous example is the Reachy robot by Pollen Robotics [20] (Fig. 5). The Reachy robot is an open-source, modular and fully customisable humanoid robot developed by Pollen Robotics. It allows researchers, creators and teachers to build their own AI (Artificial Intelligence) and HMI (Human Machine Interface) robotics applications. Companies frequently use it for innovative solutions to interact with employees, customers, and visitors.

Fig. 5. *Reachy, an open source social robot [20].*

The Reachy robot's source code, mechanical specifications, CAD (Computer-Aided Design) models, and tutorials are openly distributed [20].

2.5 Semubot and Conclusion on Social Humanoid Robots

SemuBot is an open-source social humanoid robot intended for paediatric rehabilitation. It aims to help kids who struggle with socialisation. Semubot must be an easy and safe robot even if you are unfamiliar with robotics, mechatronics, programming and electronics. To make Semubot fully customisable, it must be an open-source project.

It should be a humanoid robot to make Semubot communicative and helpful in child treatment, thus sharing some features and appearance with humans. One of the most critical human-like features is a rounded head. The head of the Semubot must not be cube-shaped like the Misty robot's [16] (Fig. 2) head and the Reachy robot's [20] (Fig. 5) head. However, the face of the Semubot must be able to show a broad spectrum of emotions, as facial expressions play an essential role in human communication [5]. Therefore, Semubot cannot have a plastic face similar to the face of the Pepper robot [19] (Fig. 4).

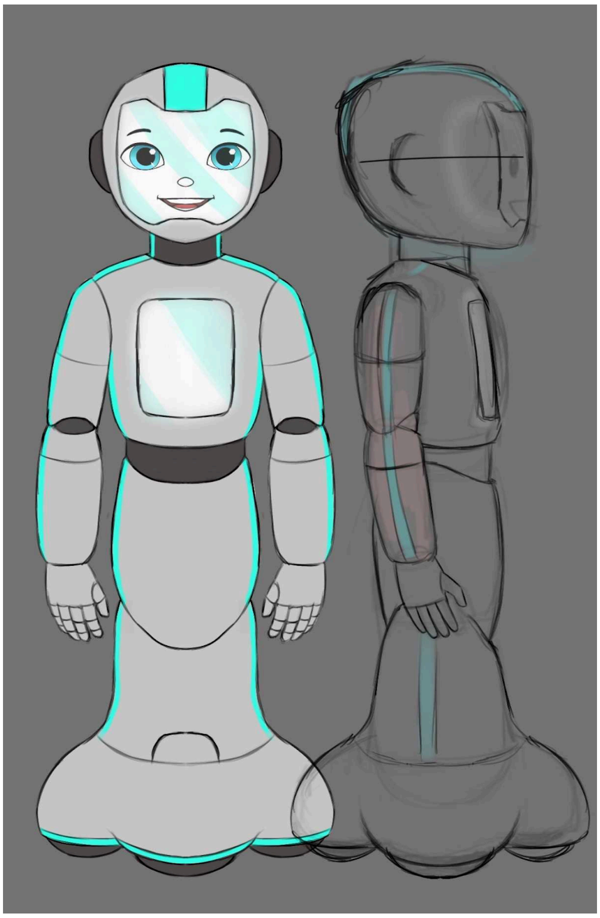


Fig. 6. *Semubot illustration.*

2.6 Screens and Displays

The initial idea for the Semubot's face was to use a projector that could be placed inside the robot's chest and utilise a mirror to reflect the light from the projector onto a curtain that plays the role of a face. However, this concept was insufficient as the user experience of using this face is terrible. This idea's main issue is that the projector's light keeps beaming beyond the curtain, which leads to the light flashing into the user's eyes.

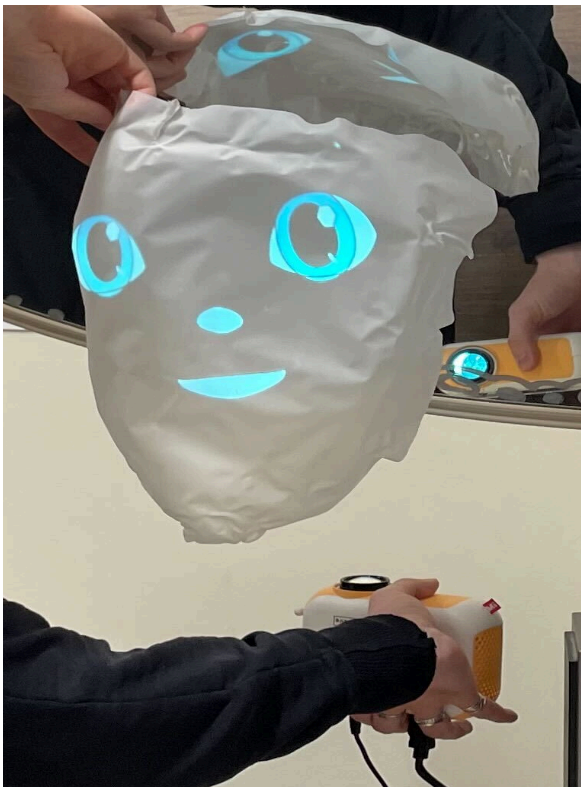


***Fig.* 7.** *Projected face example.*

That is why I have decided to use a flexible display for the face of the Semubot.

2.6.1 Flexible Displays

Flexible displays are advanced screen technologies that maintain functionality while bending, folding, or rolling. Unlike traditional rigid displays that use glass substrates, flexible displays typically employ plastic, metal foils, or thin glass substrates, enabling pliability [21]. The core principle behind their flexibility lies in using organic light-emitting diodes (OLEDs) or other flexible thin-film transistor (TFT) technologies, which can be deposited on bendable materials without compromising performance [22]. Recent innovations have also integrated flexible encapsulation methods to protect the display components from environmental factors. These advancements enable various applications, from foldable smartphones to rollable televisions, highlighting the transformative potential of flexible displays in consumer electronics and beyond.

Fig. 8. *Flexible display example*.

However, just like regular rigid displays, there are many different types of flexible displays. Choosing a proper display type is another topic the Semubot project must solve.

2.6.2 Display Type Comparison

There are many different screen types; however, the most common types are LCD, LED, OLED and AMOLED [42].

Liquid Crystal Display (LCD) technology utilises liquid crystals sandwiched between polarising filters and electrodes to control light passage and create images. When an electric current is applied, the liquid crystals align to modulate light transmission, producing the desired colour and brightness [23]. This technology is widely used in various applications, from televisions and computer monitors to digital watches, due to its efficiency and capacity for high-resolution displays.

Light-Emitting Diode (LED) displays employ an array of LEDs as the light source, either as a backlight for LCDs or as individual pixels in a direct-view configuration. The principle behind LED displays involves electroluminescence, where the diodes emit light when an electric current passes through them [24]. This technology is favoured for its high brightness, energy efficiency, and ability to produce vibrant colours and deep contrasts, making it ideal for various applications, from televisions to digital signage.

Organic Light Emitting Diode (OLED) displays utilise organic compounds that emit light when subjected to an electric current, functioning on electroluminescence [25]. Each pixel in an OLED display comprises organic materials that produce light directly, allowing for self-illumination without needing a backlight. This results in displays with superior contrast ratios, true blacks, vibrant colours, and greater flexibility in form factor, making OLED technology particularly suitable for high-end smartphones, televisions, and flexible screens.

Active Matrix Organic Light Emitting Diode (AMOLED) displays integrate a thin-film transistor (TFT) array that actively controls the current flowing through each pixel, enhancing the performance of OLED technology [26]. This active matrix structure enables faster pixel switching and higher refresh rates, resulting in superior image quality, reduced motion blur, and improved energy efficiency compared to passive matrix OLEDs. The combination of OLED's self-emissive properties with the active matrix system allows AMOLED displays to deliver vibrant colours, deep blacks, and excellent contrast ratios, making them ideal for high-resolution smartphones, wearable devices, and other advanced display applications.

Articles will be revised to find the best-suiting type of screens for Semubot’s face regarding user perception and power consumption. The comparison will not consider LED displays due to the low variety on marketplaces.

2.6.2.1 OLED vs LCD

For example, the article "Image Quality Comparison between LCD and OLED Display" by Garam Seong et al. [28] presents a comprehensive study comparing the image quality and user preferences between OLED and LCDs. The researchers conducted a series of surveys and experiments to evaluate various image quality attributes such as vividness, brightness, contrast, and overall preference. Participants who were unaware of the display type viewed HDR (High dynamic range) videos on both OLED and LCD screens and provided feedback on specific quality attributes.

The findings revealed that OLED displays were generally preferred over LCDs, particularly for their vividness and perceived overall brightness. This preference is attributed to OLEDs' higher colourfulness, even when the colour gamut is similar. However, OLEDs were less favoured for naturalness, especially when displaying skin tones that appeared overly saturated.

In their article "OLED versus LCD: Who Wins?", Zhenyue Luo and Shin-Tson Wu [29] examine the comparative strengths and weaknesses of OLED displays and LCDs to determine which technology might dominate the market. The researchers conducted a detailed technical comparison based on several performance metrics, including colour saturation, response time, thinness, flexibility, energy savings, resolution, ambient contrast ratio, lifetime, and viewing angle. Their analysis revealed that OLED displays excel in colour saturation, response time, and flexibility due to their emissive nature, allowing for individually controlled pixels and thin, flexible structures. However, if a static picture is displayed, OLEDs have a shorter lifespan than LCDs. LCDs are generally more durable but suffer from slower response times and limited colour gamut due to their reliance on a backlight.

The overall information can be represented in the following table.

Table 1. *Parameters of OLED and LCD [30].*

Parameter	OLED	LCD
Contrast Ratio	Infinite (due to true blacks)	Varies, typically around 1000:1 to 5000:1
Colour Gamut	Wide, can cover nearly 100% DCI-P3	Wide, but usually less than OLED
Viewing Angle	Almost 180 degrees	Reduces colour accuracy at acute angles
Response Time	Less than 1ms	Varies, typically 1ms to 5ms
Lifespan	Shorter, varies based on usage.	Longer, can be over 100,000 hours.
Risk of Burn-In	Yes, especially with static images	No
Brightness	Varies, can be less than high-end LCD displays.	High, particularly with LED backlighting

Parameter	OLED	LCD
Energy Efficiency	More efficient with dark images	More efficient with bright or white images

2.6.2.2 AMOLED vs LCD

AMOLED type mostly shares features with OLED type. Therefore, most of the information about OLED screens also applies to the AMOLED type. However, there is an article that focuses on a comparison of AMOLED and LCD screens.

In their study titled "Does AMOLED Screen Perform Better Than LCD Screen?", researchers from Fudan University and Shanghai Everdisplay Optronics investigated the performance differences between AMOLED and LCDs [31]. The experiment involved 30 participants who completed tasks involving brightness adjustment, subjective evaluation, and visual object recognition on both types of screens. The study found that the AMOLED display required significantly lower luminance to achieve the same perceived brightness as the LCD screen, indicating better power efficiency.

Subjective evaluations revealed that participants preferred the AMOLED screen, finding its images more saturated and vivid. Furthermore, the visual object recognition task showed significantly higher accuracy on the AMOLED display than the LCD. These results suggest that AMOLED screens save more power and provide a better visual experience regarding colour saturation and clarity.

2.6.3 Display Type Choice and Conclusion

Based on that information, I have decided that the best option for the face of the Semubot is using OLED or AMOLED screens. They both share features essential for the face of the Semubot and significantly outperform LCDs in terms of user perception and power efficiency. Higher contrast, wide colour gamut, wider viewing angle and lower response time are features that are needed to provide a better user experience. Moreover, the negative features of OLED and AMOLED screens have little effect. Firstly, a worse representation of human skin tones on OLED and AMOLED screens does not affect the user experience as the face of the Semubot will not be coloured as a human skin tone. Secondly, since the face of the Semubot will not represent a static picture but rather a moving facial expression, the lower lifespan of the screen will not be an issue. Lastly, as the face of the Semubot will most likely consist of eyes and a mouth drawn on a black background, OLED and AMOLED screens will be better regarding power efficiency.

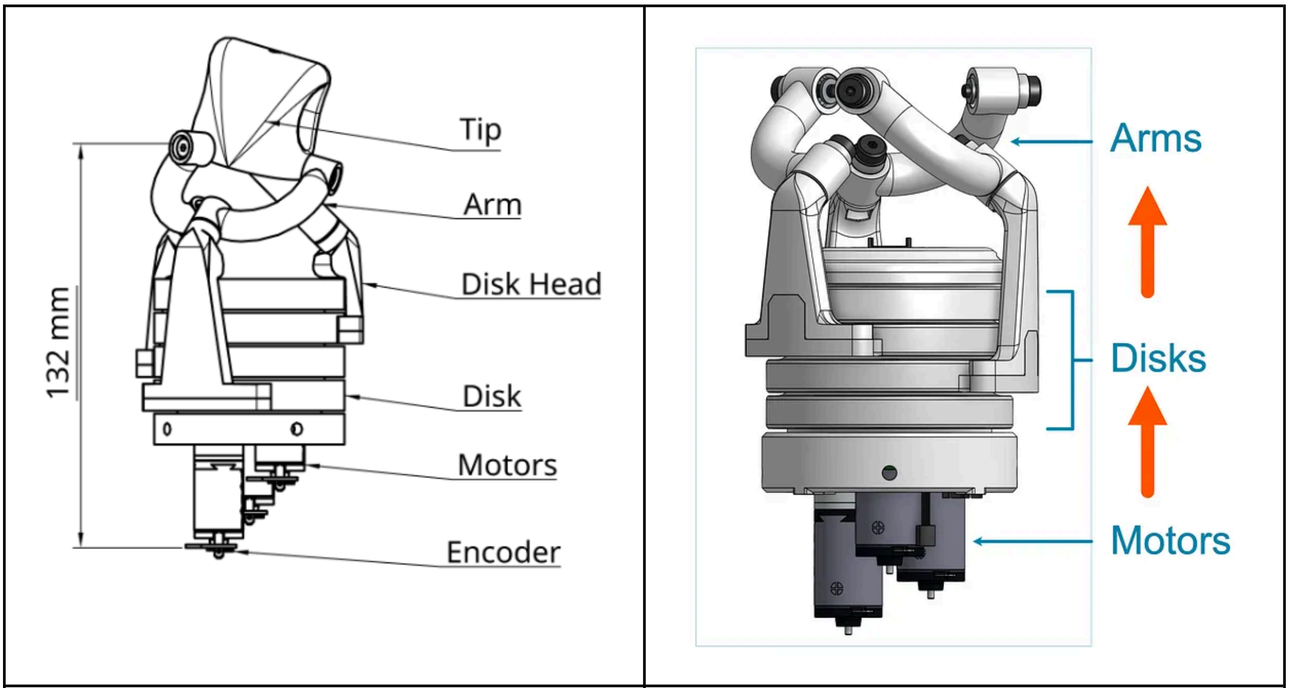
This way, for the SemuBot project, the priority is given to OLED/AMOLED screens as they have higher contrast and more extensive colour range and are a bit more power efficient than LCDs. The choice between OLED and AMOLED will be made based on the price of the screen itself and its size.

2.7 Neck Mechanisms in Robots

However, a head cannot just float in the air. That is why, in this section, I will review some of the existing robotic neck solutions. As mentioned above, neck and head motions are essential in human communication [6]. Therefore, to make the Semubot a great social robot, it must be provided with a good neck mechanism.

2.7.1 Reachy Robot Neck Mechanism

Thanks to the open-source nature of the Reachy robot (Fig. 5), it is possible to see its specifications and learn the idea behind the neck mechanism of the robot. According to the datasheets, the Reachy robot's neck is based on an Orbita neck joint developed by Pollen Robotics' R&D team [32]. Drawing inspiration from living creatures, the developers aim to mimic natural interactions rather than directly imitate them. Unlike the traditional serial system, the Orbita actuator provides a 3-DOF movement by utilising three motors working in a parallel system. This configuration ensures that all three rotations co-occur in 3D space, avoiding issues like offset rotations and gimbal lock and providing smooth, accurate, and powerful head movements. The motors in Orbita simultaneously actuate three disks (Fig. 9 (b)), (Fig. 10), which, through connected arms (Fig. 9 (a)), rotate the end effector.



(a) Schematic View

(b) CAD Model View

Fig. 9. *Reachy Robot neck mechanism [34] [33].*

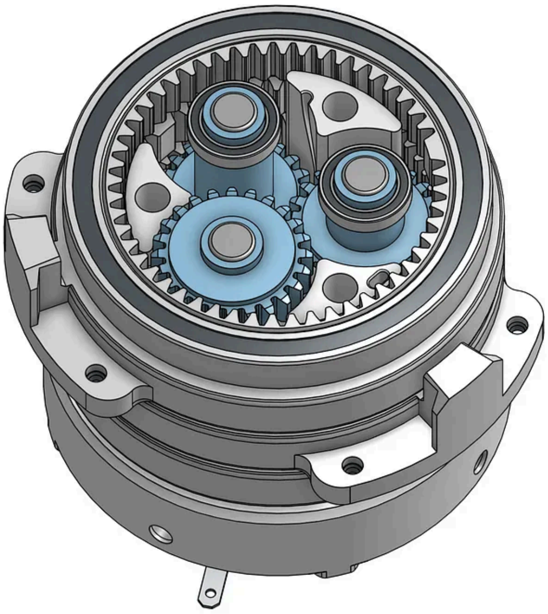
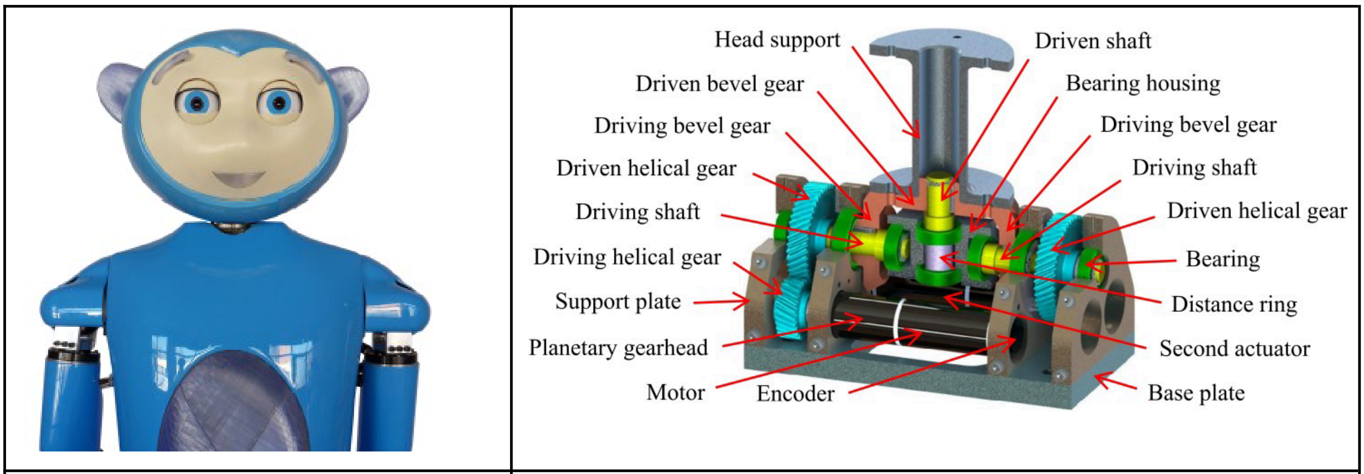


Fig. 10. *Reachy Robot neck mechanism inside [33].*

2.7.2 MARKO Robot Neck Mechanism

The article [35] presents the development of the neck mechanism for the humanoid robot MARKO (Fig. 11 (a)), designed as an assistive device for physical therapy in children with cerebral palsy. The robot aims to make therapy more engaging for children by acting as a partner who can demonstrate exercises. The neck of MARKO has two degrees of freedom (DOFs), allowing for flexion-extension up to 100° and rotation of ±90°. The neck uses a differential mechanism with three spiral bevel gears—two driven and one driven (Fig. 11 (b)). This configuration enables the neck to perform complex movements with high precision and repeatability.

The mechanical design features two identical parallel gear mechanisms to transmit power from the actuators to the differential mechanism, ensuring high efficiency and reliability. The neck mechanism is compact, lightweight, and has low backlash, contributing to its positioning and movement accuracy. The overall dimensions of the neck are 164 mm in width, 84 mm in length, and 92 mm in height, with a mass of 2 kg. The driving system includes two Maxon EC-max 22 motors with planetary gearheads, providing the necessary torque and speed for neck movements. The differential mechanism allows the head to move about the pitch axis when both driving gears rotate at the same speed and direction and about the yaw axis when they rotate in opposite directions. Combining these movements is possible when the gears rotate at different speeds.



(a) MARKO Robot Appearance [35]

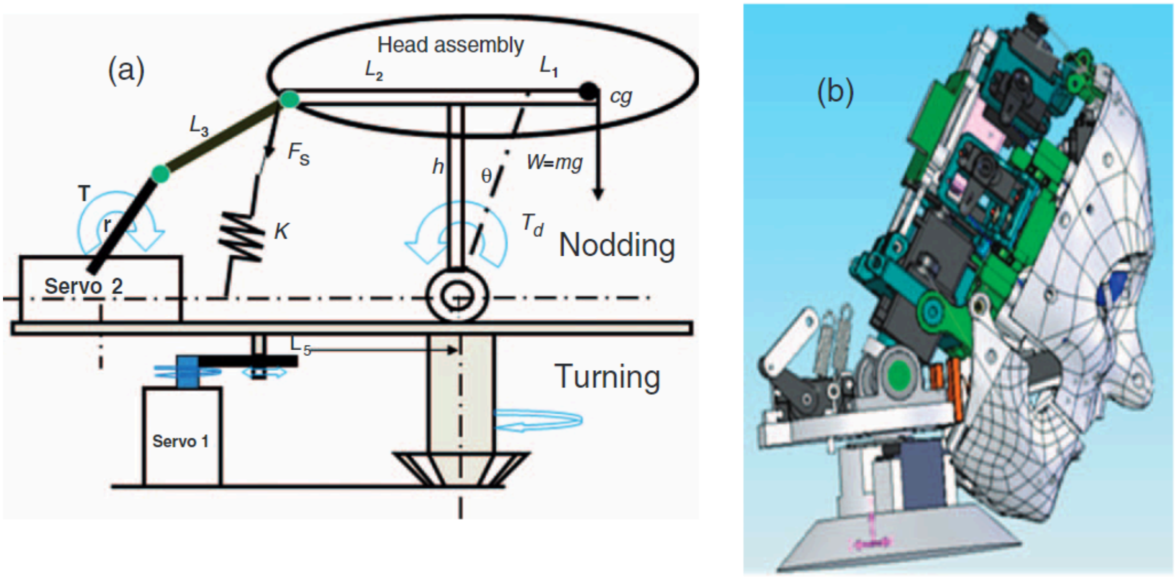
(b) MARKO Robot's neck mechanism [35]

Fig. 11. *Marko Robot [35].*

2.7.3 Humanoid Neck with Serial Chain Four-bar Mechanism

The article "Realizing a Humanoid Neck with Serial Chain Four-bar Mechanism" by Yonas Tadesse et al. [36] presents the design, fabrication, and characterisation of a humanoid neck with two degrees of freedom utilising a serial chain four-bar mechanism (Fig. 12). This mechanism enables both nodding and turning movements, mimicking the natural motions of a human neck. The design features a high-torque servo motor that drives the head assembly while minimising torque requirements by positioning the drive motor away from the rotation axis. This arrangement allows the use of low-cost RC servo motors.

The neck's structure incorporates pre-tensioned springs to counterbalance the eccentric centre of gravity of the robotic head, ensuring static equilibrium when the servos are inactive. The head assembly, equipped with two CCD cameras for vision, integrates seamlessly with the neck, providing a realistic range of motion. Using an external PD controller mitigates the inherent overshooting common in servo motor dynamics, resulting in a motion profile similar to that of a biological neck.



(a) Schematic diagram of the turning and nodding mechanism	(b) The forward motion of the head

Fig. 12. Serial Chain Four-bar Humanoid Neck Mechanism [36]

2.7.4 Conclusion of Neck Mechanism Revision

Based on the review, existing solutions do not satisfy the Semubot requirements. Semubot's head will have a human head-like appearance, so complex neck motion movement is not preferred. Semubot's primary goal is to be cute for children. That is why I and the design team decided that the most appropriate amount of DOF is 1. This is because the mimicry of a whole human neck motion range combined with a human-like head might be terrifying for children. However, 2 DOFs might be considered for a design in future iterations of the Semubot.

Existing solutions for neck motion might be not only terrifying but also too complex for a Semubot project, leading to higher expenses. Some of the solutions are also too massive and require a lot of space, leading to the increase in size of the Semubot. Therefore, the 1 DOF neck mechanism will be developed to meet the Semubot requirements.

3 AIMS OF THE THESIS

3.1 Creating a face and a neck mechanism for the Semubot

My thesis work is part of a student project whose aim is to create a social humanoid robot, SemuBot, that can be potentially used as a communication trainer in the therapy of children with special needs. In the project, my goal is to find and implement the solution for the face of the and develop and integrate the neck movement mechanism for the robot.

3.1.1 Requirements for the Neck Mechanism of the Semubot

- The Design of the head assumes it to be rounded, so the face has to be curved
- The Face must be able to represent a wide range of emotions

3.1.2 Requirements for the Face Solution of the Semubot

- There must be a possibility to wire-connect components from the head via the neck
- Neck mechanism should have 1 Degree of Freedom as a spin motion

4 EXPERIMENTAL PART

4.1 Methods of the Work

For building the face and neck structure of the Semubot CAD program and 3D printing were utilised.

Fusion 360, developed by Autodesk [37], was used as a CAD program for developing models.

Original Prusa 3D printers and Bambu Lab X1-Carbon Combo 3D Printer were used for printing models.

Corresponding software for slicing was used: PrusaSlicer [38] and Bambu Lab Studio [39].

4.2 Face of the Semubot

The choice for the screen for the face was made towards an AMOLED screen by Wisecoco (Fig. 13). It has a perfect size for being used as the face of 7.8 inches, and its cost is much lower than other options (with the cost of around 150 Euro it is cheaper than many other products on market by few hundreds of Euro). It also requires a driver, which can be ordered with the screen itself. The screen also requires an HDMI to HDMI mini cable for image transmission and a USB-C cable for power.

Fig. 13. *Flexible AMOLED Screen Wisecoco 7.8 inch*

However, the screen itself is as thin as a sheet of paper (to be more precise, its thickness is about 0.5 mm), so there is no straight possibility of just screwing it to the head. The head of the Semubot represents a plastic shell in the form of the head (Fig. 14)

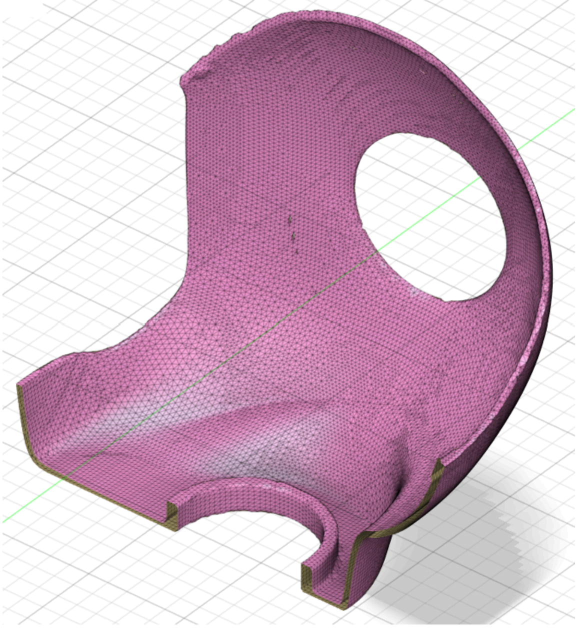
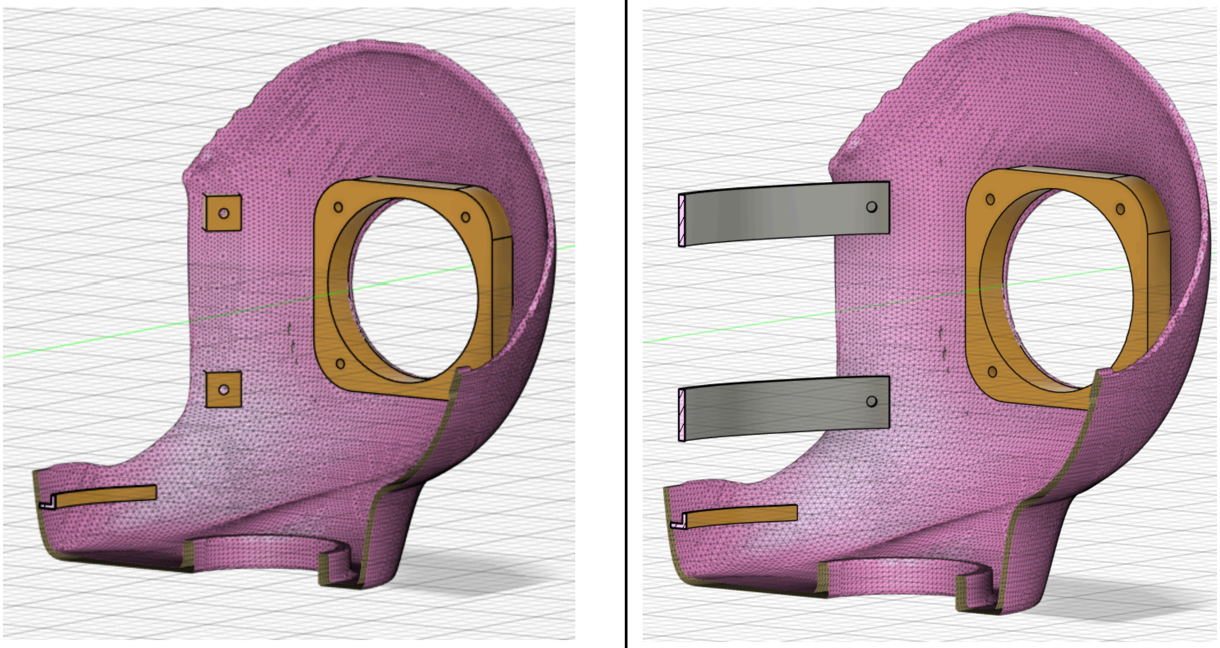
	
(a) Printed Head-shell	(b) Head-shell cross section (inside)

Fig. 14. *Head-shell of the Semubot*

To fit the flexible screen on this empty shell, I adjusted the inner design of the shell. The proposed design consists of a platform where the screen will be standing, two cubic bulges on both sides with a 4.1 mm technical hole in them for installing a heating insert screw nut bolts, and a strengthened square ear panel with four 4.1 mm technical holes for speaker installation (Fig. 15 (a)). After that, the screen is pressed down with a plastic striped plate (Fig. 15 (b)). This plate works not only like a fixer for the screen but also as an outline of the screen which enables the roundness of the face. The plate is fixed on the cubic bulges and screwed with M3 bolts. The overall amount of components for the Head-Face assembly can be represented in the following table (Table 2). Screen support plates are made of PETG (polyethylene terephthalate glycol) plastic due to their strength and relative flexibility [40], allowing the plate to bend instead of break when some sudden force is applied. The head-shell is made of PC (Polycarbonate) plastic as it provides the necessary strength to it due to its durability [41].



(a) Head-shell with modification for holding items

(b) Head-shell with screen plate-supports

Fig. 15. *Head-shell of the Semubot*

Table 2. *Head assembly components.*

Material	**Amount**
Flexible AMOLED display 7.8 inch	1
Driver for Display	1
USB-C power cable	1
HDMI to HDMI mini cable	1
PETG plastic for support plates	16.07 g
PC plastic for the head-shell	241.64 g
Heated insert M3 nut bolts	12
M3 bolts	12
Speakers (out of the scope of this thesis)	2

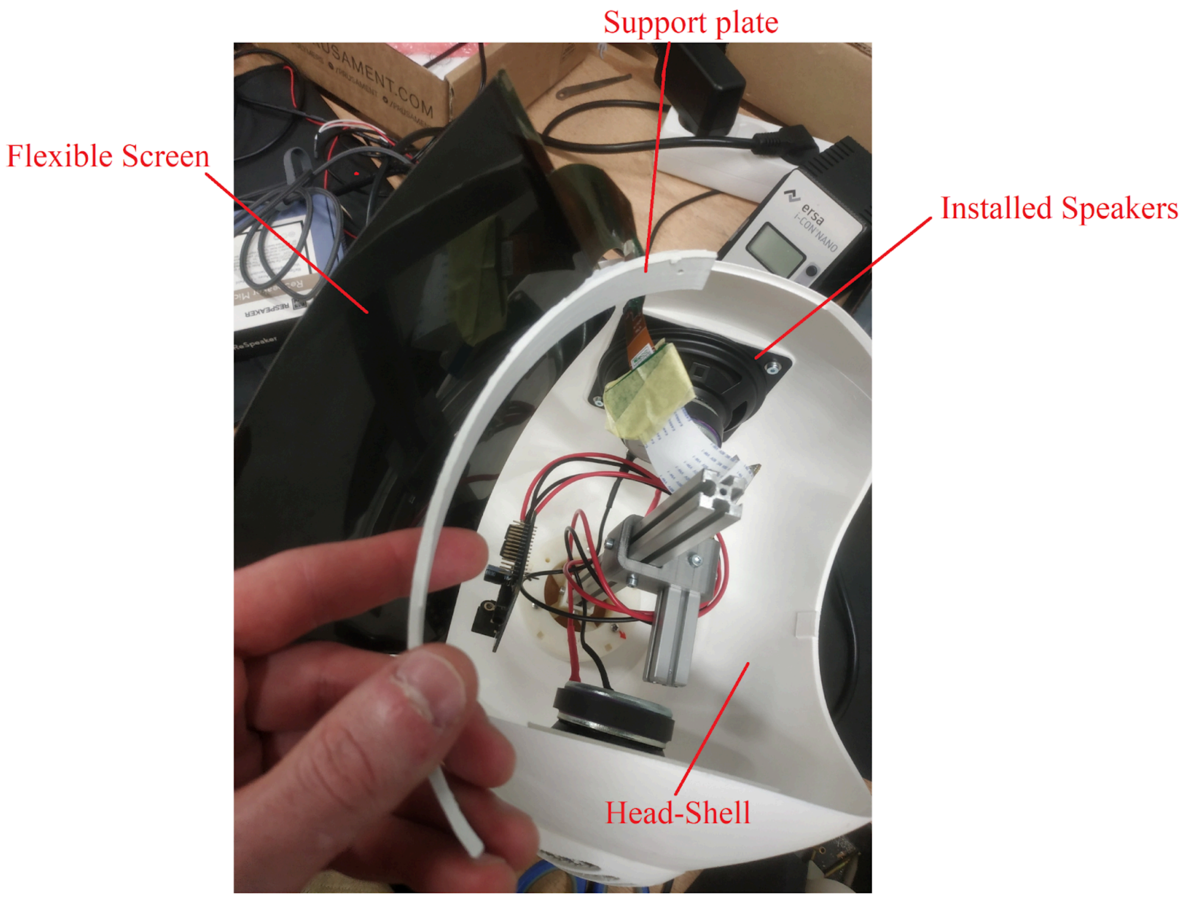
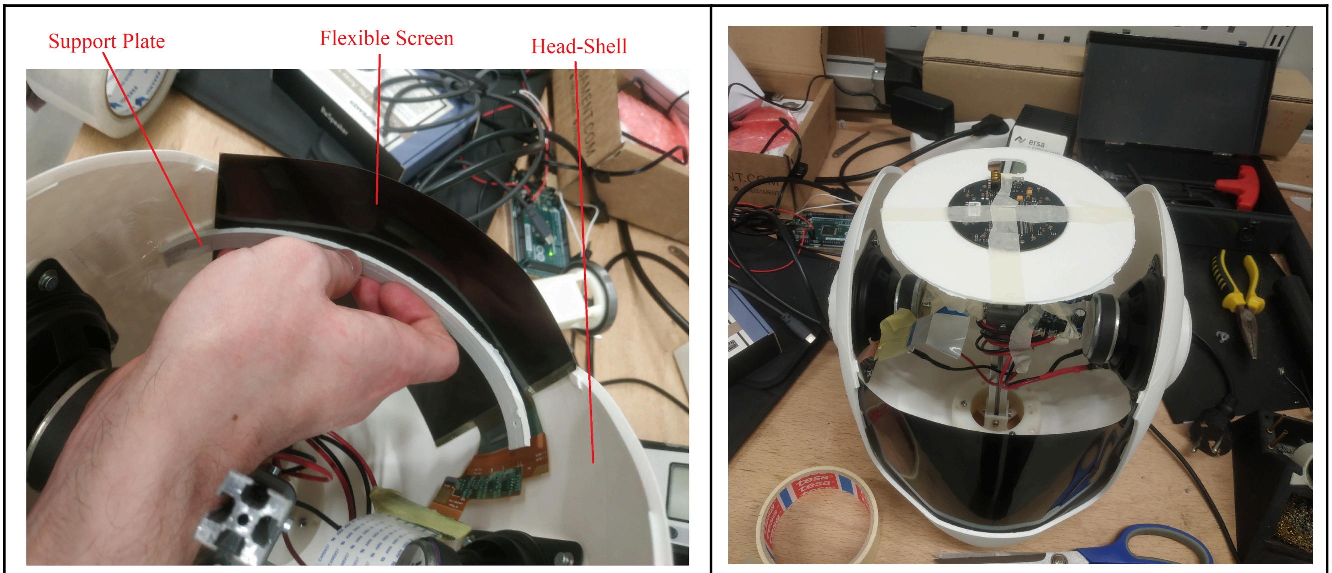


Fig. 16. *Head Assembling.*



(a) Inner view

(b) Outer view

Fig. 17. *Head Assembling.*

4.3 Neck of the Semubot

Now, after familiarising ourselves with the head appearance, it is time to proceed with the mechanism that will bear it.

Since the dimensions and weight of the head are known, finding a proper actuator is trivial. The decision was made towards stepper motors as they provide high torque and high controllability. The head weight is approximately 1 kg (Table 3), so the stepper motor should be able to carry at least 2 kg in head-spinning motion to eliminate the chance of breaking while working on the possible limits of the motor.

Table 3. *Weight of head components.*

Item (quantity)	Weight
Speakers (2)	230 g
Aluminium extrusion 15mm x 15mm x 120mm (1.5)	150 g
Other parts of the Semubot's head	347 g

The chosen stepper is a Nema 11 Stepper Motor Bipolar with a Gear Ratio of 19:1 and a Planetary Gearbox [45]. Firstly, it's a good option for applications with limited space but need low speed and/or high torque. Secondly, it was a good option in terms of ordering convenience. Most of the motors for the hand and base parts of the Semubot were Nema Steppers, so placing a bigger order is much more advantageous. Lastly, it has a frame size of 28 x 28mm, which later will be very beneficial in terms of the design.

4.3.1 Initial Concept

The initial concept for the neck movement was the idea that the stepper is located beside the aluminium extrusion that plays the role of a Semubot's spine and moves a large gear where the head is placed (Fig. 18). The head of the Semubot is placed on top of the large gear (F) that is located on a 60mm x 50mm x 7mm bearing (E) and this F item is driven by the stepper motor with a smaller gear for reduction of the momentum. This mechanism is fixed on top of the aluminium extrusion, and on top of the mechanism, there is a smaller inside head spine (H) that works as a holder for the microphone array inside the head and a placer for the amplifier and flexible screen driver.

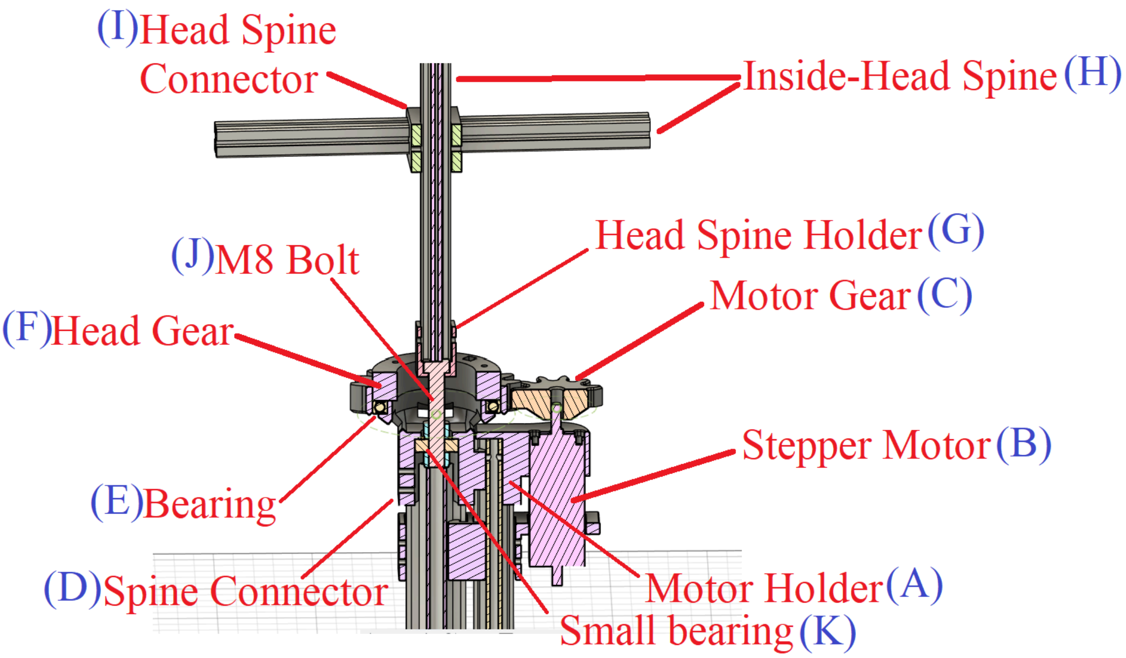


Fig. 18. *Neck motion mechanism V1.*

However, this mechanism has a lot of issues. First of all, it is massive (with a size of about 10x8 cm) and requires a lot of space (at least a 14cm in diameter neck). Semubot must not have that huge neck as the head of the Semubot has a size of 20cm in diameter. Secondly, gear reduction is unnecessary and causes some backlash. Lastly, an M8 bolt is a bad holder for a huge spine, and together with the small bearing (K) of 8x22x7mm, it also causes a backlash.

4.3.2 Proposed Neck Mechanism

The solution to this issue is basically the elimination of all unnecessary parts and leaving only essential ones. Here, I have decided to put a stepper on top of the spine extrusion 30x30mm as this stepper has a perfect frame size of 28x28mm for this purpose.

The most important part of the design is the Spine connector (Fig. 19), which is the heart of the whole neck structure. It is constructed the way that the stepper is placed inside it and, after that, fixed with the M3 bolts. A thin wall keeps the stepper a few millimetres away from the spine. After that, the connector is placed on top of the extrusion (Fig. 20) and fixed with the M6 bolts. Following, a bearing is placed on top of the connector and fixed with a special panel and four 3mm bolts (Fig. 21). On top of the bearing, a “Head Mover” (Fig. 22) is located. It transfers all of the motion from the stepper onto the head spine and a “Head Holder” (Fig. 23). Neck Mover has stiffeners for strength, holes for nut bolts and a holder for a head spine.

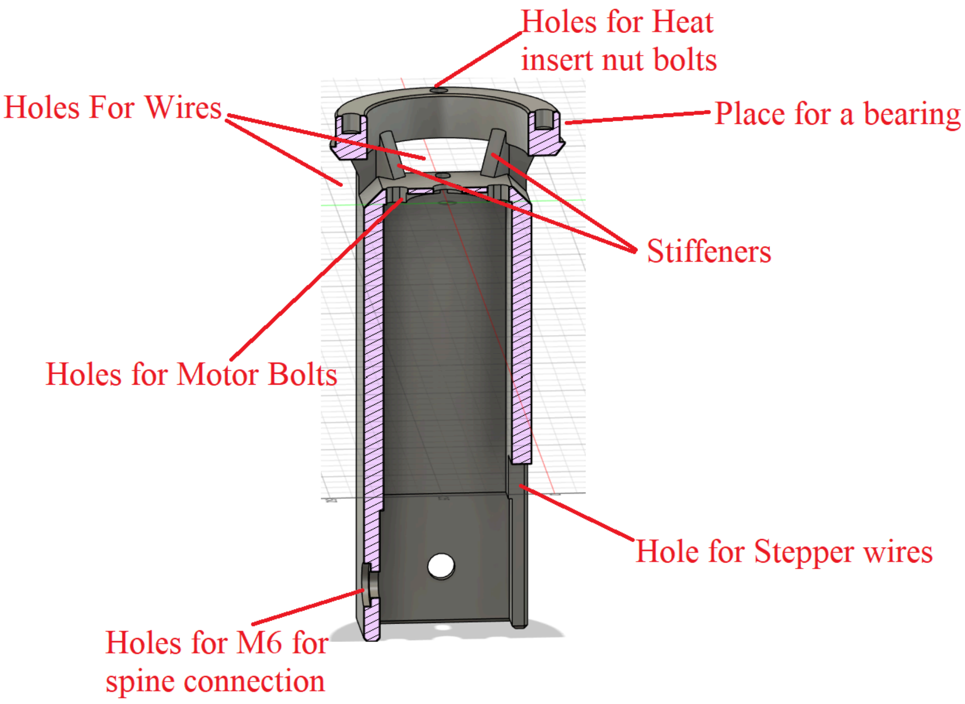


Fig. 19. *Spine Connector.*

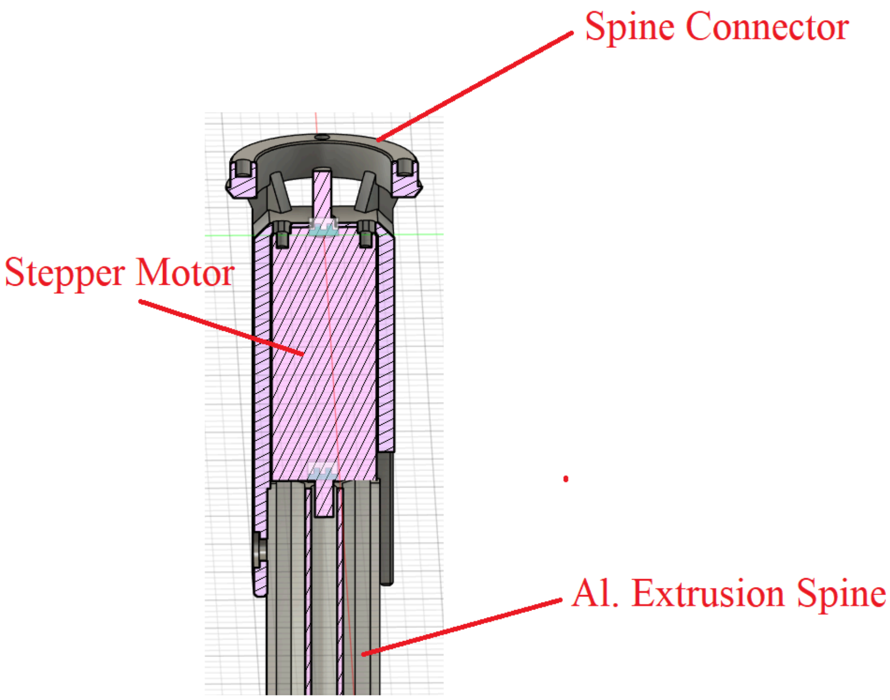


Fig. 20. *Spine, Connector and Stepper.*

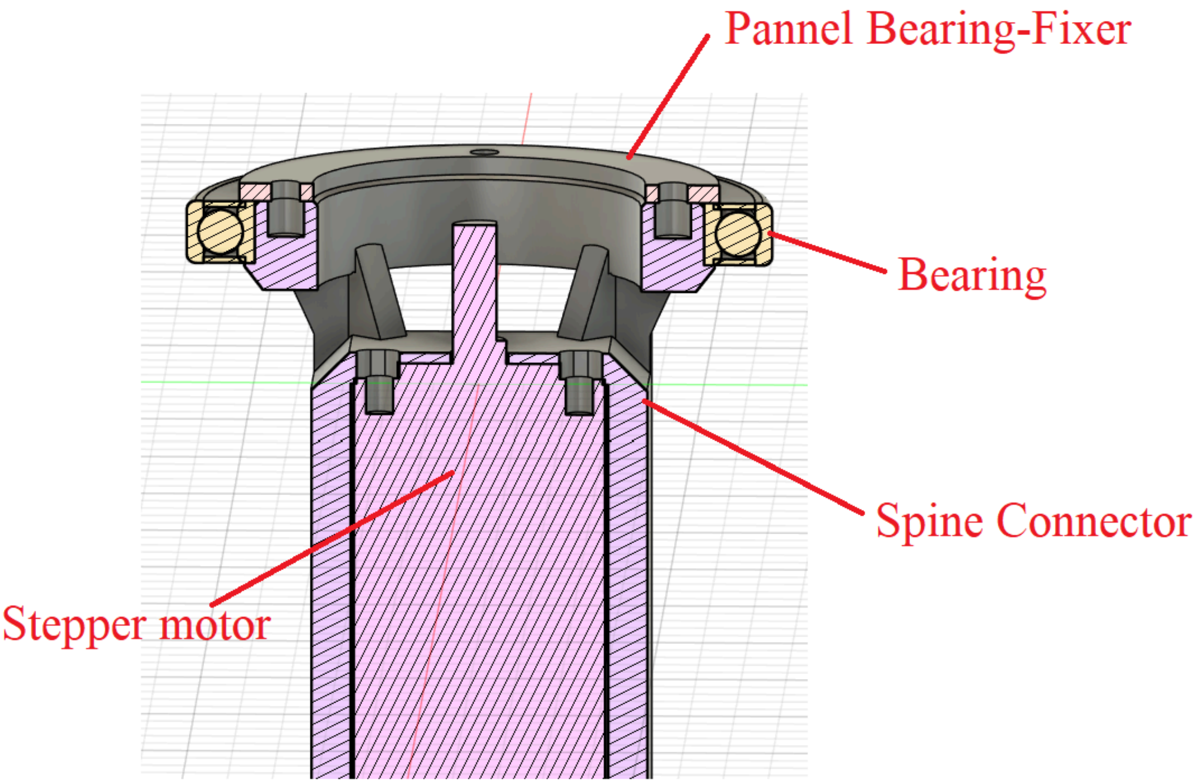


Fig. 21. *Bearing and Spine connector.*

On top of that construction, a “Head Holder” is placed. As the title states, it serves as a platform on which the head shell is placed. It also has stiffeners, debugging holes for easier bearing disassembly, and special pin holes where the “Snap-Pin holder” goes.

Snap-Pin holder (Fig. 24) is a model that utilises the flexure feature to connect to a Head Holder and fix it so the head will not fall off. The material for the Snap-Pin holder should be PETG, as it provides extra flexibility.

An aluminium extrusion of 15x15mm 12cm is used for the head spine, and it is interconnected with a 6cm extrusion with the “Head Spine connector”. On top of this vertical head spine, a microphone array holder is located and fixed with little knobs by M3 bolts. The screen driver and an amplifier are situated on a horizontal part of the head spine and fixed with the hose clamps. This aluminium extrusion cools these components as they get pretty hot during work.

In the end, a “Head Fixer” keeps the head from slipping and keeping it moving with other components (Fig. 25).

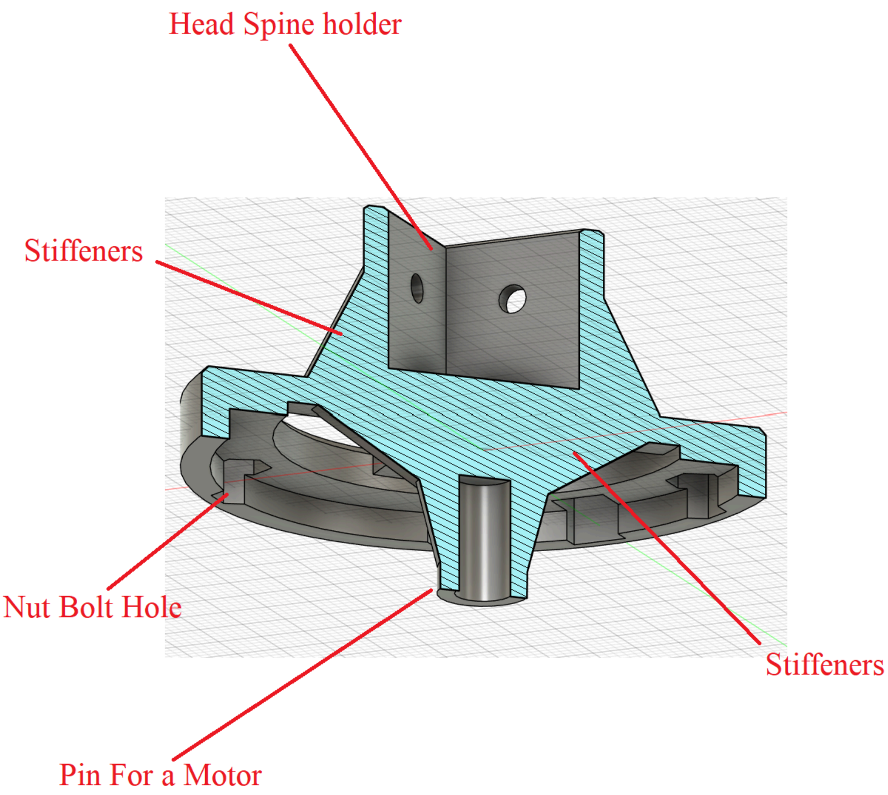


Fig. 22. *Head Mover.*

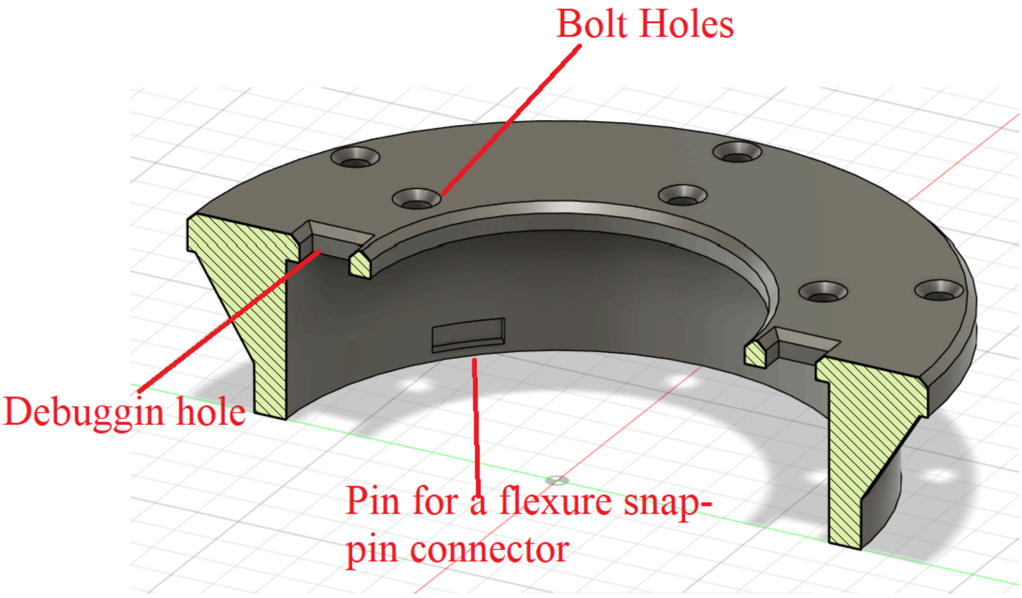


Fig. 23. *Head Holder.*

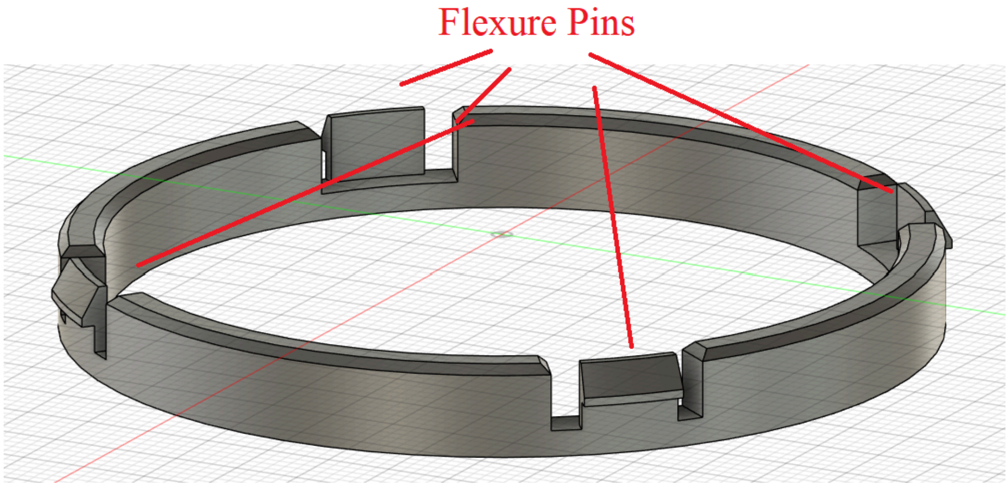


Fig. 24. *Flexure Snap-Pin holder.*

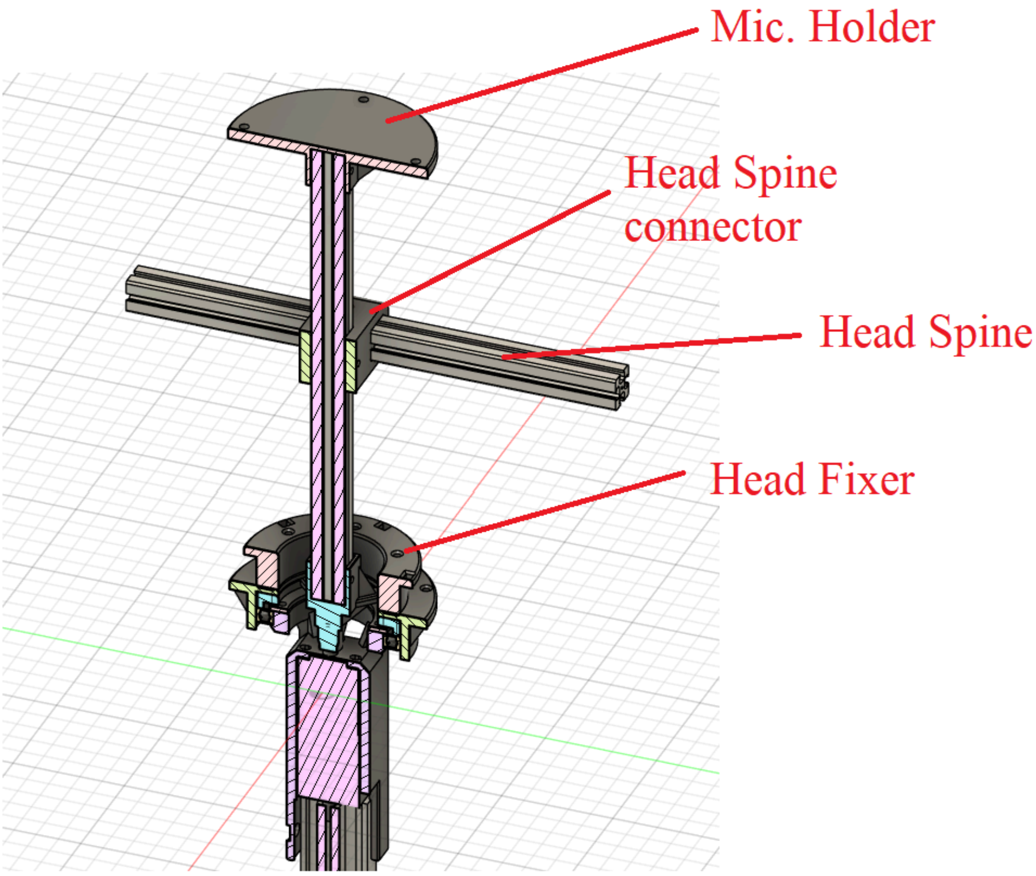


Fig. 25. *Full inside head assembly.*

All of the components except for Snap-Pin Holder are made of PC type of plastic for the stronger mechanism as PC is more durable.

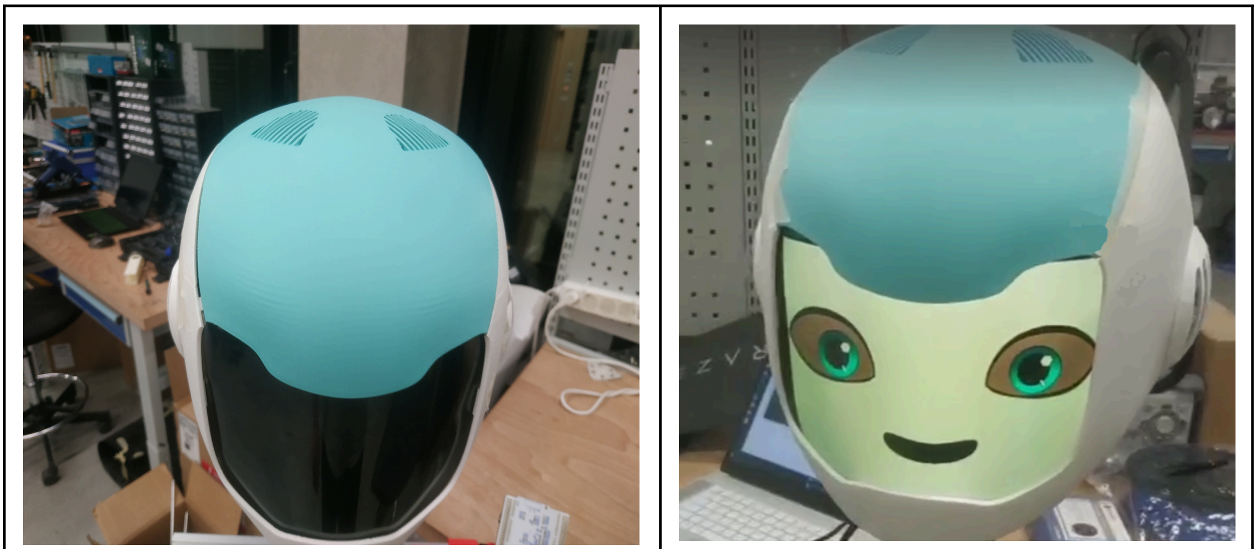
Overall, the components for the neck assembly can be structured in the following table:

Table 4. *Neck assembly components.*

Material	Amount
M3 x 25mm	6
M3 x 4	11
M3 x 6	10
M6 bolt	3
M6 T Slide Nut	3
M3 nut bolt	16
Heat Insert M3 nut bolt	8
Nemo Stepper motor	1
Bearing 65x50x7mm	1
Aluminium extrusion 15x15mm	1
PETG plastic	3 g
PC plastic	150 g
Aluminium extrusion 30x30mm (out of the scope of the thesis)	1
Arduino Uno	1

4.4 Results

The result of the work is a fully working head of the Semubot robot with a functioning face (Fig. 26) and neck mechanism (Fig. 27). A neck of the robot is strong enough to carry a 1 kg head and even withstand a small stress test (force that was manually applied towards head and neck). A face is able to show any kind of video, picture or GIF information allowing for designing any kind of face for the robot.



(a) Flexible Screen is OFF

(b) A random image for the representation

Fig. 26. *Assembled Head.*

Fig. 27. *Assembled Neck Mechanism.*

Fig. 28. *Semubot.*

4.5 Discussion

The result of the work is pretty satisfactory, however there is a potential for modifications.

One possible modification is replacing the screen's support plates with a full solid plastic wall that works as a supporter. This way, the face will be stronger and more durable on uncertain occasions.

Secondly, the current neck mechanism is locked with a 180-degree motion, which is enough for a social robot. However, there might be a wire twist, which will lead to a component disconnect. Although the chances of that happening are quite low, a modification of a slip ring wiring system (Fig. 29) might be considered in the future. So, as a 2 DOF motion range of a neck.

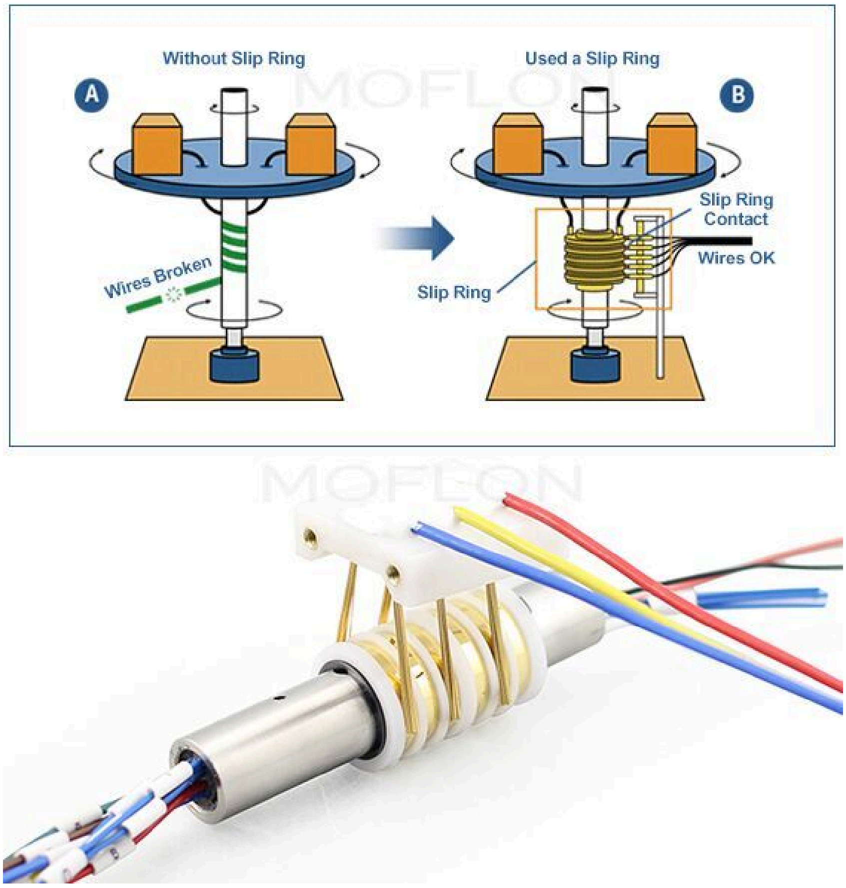


Fig. 29. *Slip Ring Wire System. [41]*

SUMMARY

This thesis presents significant advancements in designing and implementing a humanoid robot, specifically focusing on enhancing its expressiveness and interaction capabilities. A major achievement of this work is the successful integration of a flexible screen, which enables the robot to display dynamic and realistic facial expressions. This feature is crucial for creating more lifelike and relatable interactions, particularly in social and educational contexts where non-verbal communication plays a key role.

Developing an advanced neck mechanism that allows for a wide range of head gestures further contributes to the robot's expressiveness.

The research and development efforts documented in this thesis are part of a larger project to create Semubot, an open-source social humanoid robot. Semubot is designed to aid in training children's communication skills, leveraging its advanced expressive features to provide a more engaging and interactive learning experience. The integration of these sophisticated components—flexible screens for facial expressions and a versatile neck mechanism—marks a substantial step forward in the field of humanoid robotics, enhancing the robot's ability to interact in a manner that is both engaging and relatable to humans.

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