Tabletop social robot

Karlsruhe Institute of Technology

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Résumé

Ce stage à l'Institut de Karlsruhe en Allemagne avait pour objectif la conception, le design 3D, la construction et la programmation d'un robot sur table qui détecterait les mouvements et encouragerait des employés de bureau à faire des pauses régulières pendant leur journée de travail s'il observe qu'ils restent trop sédentaires. La première partie de ce stage s'est concentrée sur une analyse du public cible et de leurs besoins précis, suivi d'une première idée de design général du robot. Ensuite, une grande partie du stage fut dédiée à la conception 3D des pièces du robot, puis à la production de ces pièces par impression 3D, et enfin l'assemblage du corps du robot. La fin du stage fut passée à développer le circuit électronique du robot : ce dernier est controlé par une Raspberry Pi 4, qui pilote les servomoteurs actionnant ses différents membres. A la fin de ce stage, le robot est construit et peut prendre un certain nombre de positions pré-définies indiquant si l'utilisateur doit prendre une pause ou non. Pour rendre le robot opérationnel, il reste maintenant à lier ces positions à une caméra de détection de mouvement : une fois cela réalisé, il faudra tester le robot pour confirmer ou non son efficacité.

Mots clés

Robotique sociale, Conception assistée par ordinateur (CAO), impression 3D, santé au travail, Raspberry Pi.

Abstract

The goal of this internship at the Karlsruhe Institute of Technology in Germany was to design, build, and program a tabletop social robot tasked with seeing if their user is sitting down too long and if that is the case, motivate them to get up and take a break for their health. The first part of the internship was spent analysing the potential users of the robot and their needs, and establishing the general design for the robot's shape. Next, a significant part of the internship was spent designing the different parts of the robot, printing these parts with a 3D printer, and then assembling the robot's body entirely. Finally, the last part of the internship was spent working on the electrical components of the robot : it is controlled by a Raspberry Pi 4 that actions the servomotors making the different body pieces move. A the end of the internship, the robot is fully built and has a set of positions pre-programmed that indicate whether or not the user should take a break. To make the robot operational, these positions have to be linked to a motion detecting camera : once this is done, the robot has to be tested on a significant enough sample of people to confirm its efficiency.

Keywords

Socially assistive robot, Computer aided design (CAD), 3D printing, occupational health, Raspberry Pi .

Acknowledgements

Many thanks to everyone at the SARAI Lab that welcomed me warmly to KIT and helped me discover the different research one can do in Socially Assistive Robotics. To Victoria, Oliver, Yasmin, Xiyu and Katharina, I enjoyed sharing the best (but unfortunately hottest) lab room of InformatiKOM with you all, and I hope you continue to have success in all your endeavors for now on. To Romain, your guidance during the internship was invaluable, whether it was to debug the 3D printer on a Saturday afternoon or to help me choose the best meals at the Mensa. To Barbara finally, I can not thank you enough for the opportunity to work at SARAI for my internship, and for all I learnt from you during those months : I wish you all the success that could come your way, and I hope the ranks of the SARAI Knights and the Espresso Warriors never stop growing.

Contents

1 Introduction

1.1 Research laboratory overview

This internship took place at the Karlsruhe Institute of Technology (KIT) in Germany, in the Department of Informatics. The Department of Informatics of KIT is home to several research groups, and notably the Institute for Anthropomatics und Robotics (IAR) , which heavily focuses on human-oriented robotics and how modelling human behaviour as best as possible can help improve technical systems by making them more people-friendly. Within IAR, this internship took place in the research group "Socially Assistive Robotics with Artificial Intelligence" (SARAI) : this group has at its main objective the design, development and testing of robots that interact directly with humans and provide assistance to them. SARAI is led by Dr. Barbara Bruno, who was also the supervisor of the internship.

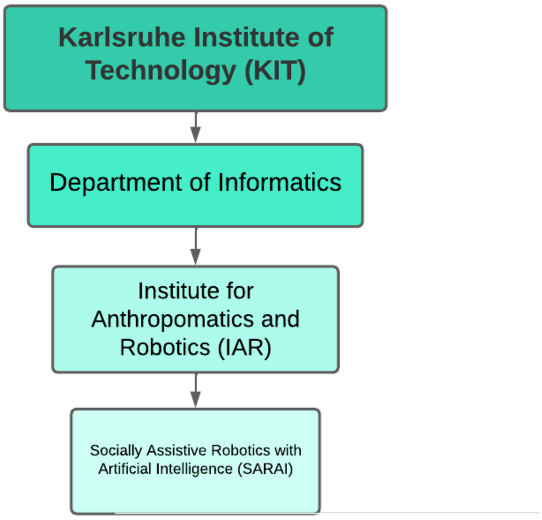

Figure 1: Partial Organisational structure of the Karlsruhe Institute of Technology (KIT)

1.2 Problematisation

1.2.1 General concept of socially assistive robots

The focus of the SARAI Lab is the development and testing of socially assistive robots. The goal of socially assistive robots is to provide assistance to humans in need of their services, and this assistance is carried out via social interaction. Due to their social aspect, developing these robots require for several things to be taken into account when it comes to the way people interact with them. Indeed, many factors come into play when it comes to robot-human interactions such as age, education, but also more broadly culture[1] : people across the world will have different ways of greeting each other, of asking questions, different notions of what politeness looks like... there is no "universal" social robot that would fit globally[**?**].

1.2.2 Use of robots for health related issues

Socially assistive robots are meant to be used in people's lives in various ways. Some are used to help teach, notably small children, others can be used to improve day to day life by helping people adopt better behaviors. This application is notably useful when it comes to health, and more specifically physical activity. For many people, regular physical activity is not an easy habit to form : according to the OECD, in 2019 only 32% of adults in the European Union performed at least 150 minutes of physical activity per week on average[3].

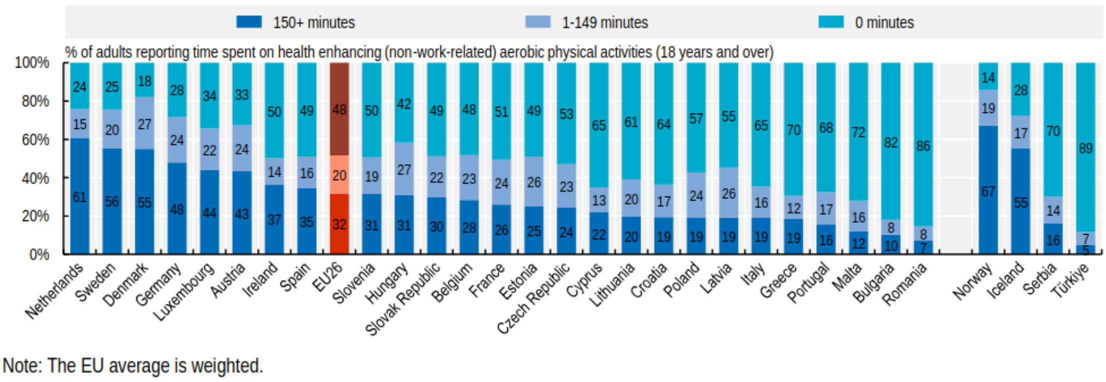

Figure 2: Time spent on physical activity among adults, 2019 (source: Eurostat, 2022)

To help people be more active, one of the easiest solution is to encourage them to increase a very simple form of physical practice : walking. Walking has been shown to have many benefits on people's health. It helps in preventing heart attacks and in the treatment of many disorders such as hypertension, or musculoskeletal disorders [4]. In addition to being inherently safe, walking is accessible to almost everyone and, unlike many other physical activities, shows little, if any, decline in middle age[4]. On the other hand, due to the ever-growing sedentary lifestyle of society, the amount of time people spend walking is very little, which can be seen as a waste of potential for health and well-being [4]. The potential shown by social robots in human behavioural change [5] is a promising motivation for exploring their use in this context. Indeed, social robots have been used as tools to continuously monitor the physical activity of human users and provide appropriate feedback and motivation [6] and could be used in a similar manner to correct human static behaviours.

1.2.3 Goal of the internship

There were several objectives for this internship. The goal was to :

1. Follow a participatory design approach to identify the needs and requirements of the robot's user base

2. Based on the identified requirements, design, build and program a tabletop social robot able to detect if a human user has not walked or stretched for a long period of time and, in such a case, motivate them to do so

3. design a simple experiment with human participants to validate the effectiveness of the robot in performing its intended goal, evaluate the participants' perception of the robot, and analyse the results

4. Summarise the work carried out in a scientific report

This robot would be on the user's desk during the whole day, and has to interact with people in a way that convinces them to change their daily health habits : its social aspect makes it fit perfectly with the SARAI Lab's other ongoing projects. Previous studies have already shown that having a social robot is more effective to convince users to take breaks than a simple tablet[7] : this projets aims to confirm this idea.

1.2.4 What the internship brings to the SARAI Lab

For the lab, the added value of this internship was to have a more pragmatic approach to the details of the design. Indeed, many previous experiments such as [7] were done in conditions meant only for a research environment, and not a work environment. For example, the motion detectors in the experiment (a Sensor Pad and a Chair Sensor Module) were bulky and attached to the chairs : if we imagine an actual office environment, it is unrealistic to use such invasive material, and so alternatives need to be found. Likewise, there was an issue of privacy with the use of constant cameras during the day : not a problem for an experiment, but some workers might not agree with being filmed all day from up close. This issue also has to be dealt with during the design process.

2 Activities undertaken during the internship

2.1 Preliminary analysis of the project's scope

The first step before designing the robot was to identify the needs and requirements of the robot's user base. To do this, a participatory design approach was chosen, and the first two weeks of the internship were dedicated to this initial design stage.

2.1.1 Target audience

This tabletop robot aims to remind people to take regular breaks for their health : the presumed context for its use is an office environment, and potentially desktop workers that often work at home if the robot is successful in offices. The robot thus needs to be suitable for daily use, and needs to be relatively affordable: any firm with a significant number of office workers that needs to buy a robot for each of them will not want to invest too much money at once. The robot is meant to be placed on desks : both the cost and the size need to be taken into account during the design process.

2.1.2 Defining the robot's actions

The robot's mission is health-related: another important aspect of the design is making sure its impact on users' health is tangible. To learn more about what actions the robot should take to ensure its positive impact, the Sport Institute of KIT was consulted. People are more receptive to change when the motivation to change is rooted in theoretical evidence[8] : The first idea was thus to have the robot give health-related statistics to the user regularly. This idea was not followed up on as there was a risk of having these statistics be too repetitive and eventually irritating to hear over and over again. The idea chosen was to have the robot encourage movement in the user through imitation : the robot starts to move and progressively stands up before starting to address the user when it is time for a break. Depending on a person's fitness level, different actions might be beneficial during breaks. For this project, the user profile was considered to be someone with a relatively low fitness level and with a sedentary lifestyle : the robot's only mission is thus to encourage the user to take a break by taking a five minute walk, with no additional sport or stretching included.

2.1.3 Adapting the design to the limitations of the internship

Lastly, the design had to be made by taking into account the limitations of the internship, such as the time constraint and the use of affordable material. To make sure the robot would be build by the end of the four months, several choices were made to simplify the design:

- The robot is to be stationary: it can shift its position but it does not "walk" on the desk
- The robot's design is to be fully 3D-printable : the SARAi lab already had a 3D printer, meaning the cost of the robot would come down to the filament and electronic components' prices
- The robot's range of movement is to be limited to a few preset positions, with no idle movement when it is not actively interacting with users

2.2 CAD design

2.2.1 General shape

In experiments ran to test users' reactions to different types of robotic interfaces, many report a more positive perception when they felt the robot showed "expressiveness" and cuteness", and that they enjoyed it when it felt "kind of like a little pet on [their] desk"[7]. Following this observation, the robot shape was chosen to be one of a cat, with several joints controlled by servo motors to imitate a cat's limbs' movements. The robot was to be designed on the product development platform Onshape, with the goal to then print out the pieces on a 3D printer.

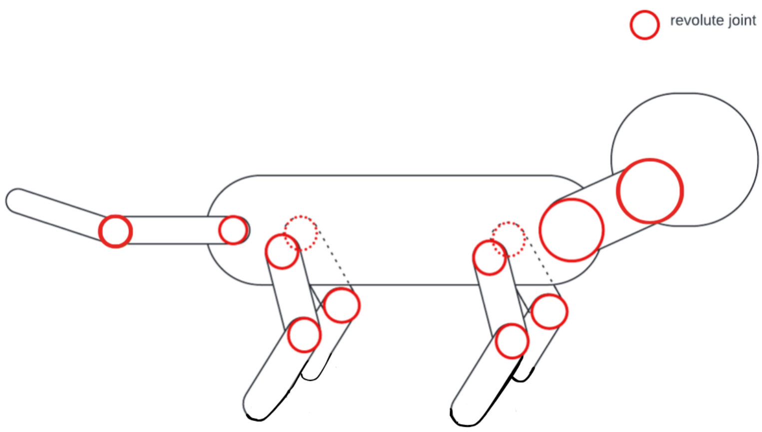

Figure 3: Basic design and joints sketch of the tabletop robot

2.2.2 First steps : main body and legs

The first step was to create the main body, and the legs. The general shape of the limbs was inspired by the robot system of the "Open Dynamic Robot Initiative" [9], as this design was easy to implement with the motors available for the project. The main limit to the robot's size was the size of the servo motors used to actuate the limbs : the upper leg was designed to be as small as possible while still accommodating the servo motor. Both the upper and lower legs were designed with a lid, to hide the electronic components once the robot is fully built.

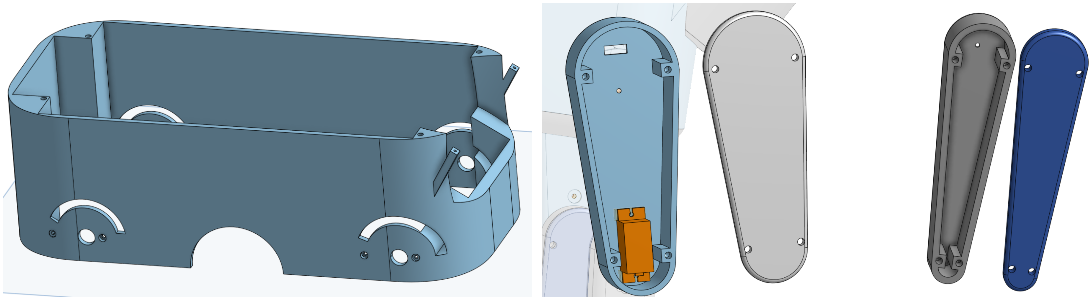

Figure 4: CAD designs of the main body, upper leg, lower leg and their respective lids

2.2.3 Upper and lower tails

The robot's tail was split in two parts: the upper and lower tail. The upper tail was designed to move left to right, and the lower tail up and down. The upper tail was attached to the main body piece via a junction piece that holds the servo motor powering it, and has a lid at its extremity that links it to the lower tail.

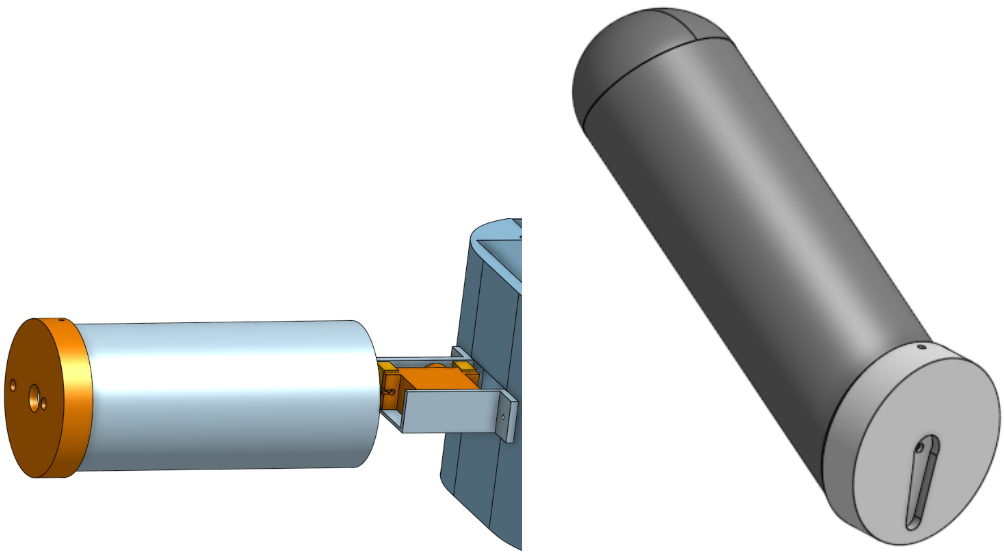

Figure 5: CAD designs of the junction piece, upper tail, lower tail and their respective lids

2.2.4 Adapting the design to accommodate the electrical components

The main body piece is open at the bottom and the top : these openings were closed by two lids, and the bottom lid was modified to accommodate the electrical components of the robot, and notably a Raspberry Pi 4 and the motor driver that pilots the servo motors. A hole was made on its side to let the wiring pass.

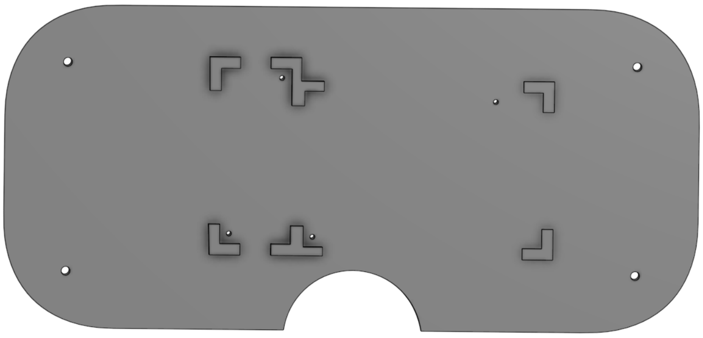

Figure 6: CAD design of the bottom lid

2.2.5 Final steps : neck and head parts

Finally, the only remaining parts of the robot to design was the neck and head area. There were several challenges for this part of the design. First of all, it was necessary to find a balance between making the neck sturdy enough to carry the weight of the head, and making it possible for the head to move side to side. This head movement was assured by a servo motor connecting the head and the neck, and the neck was designed to be fastened on the top lid of the main body, which ensured it was secured properly.

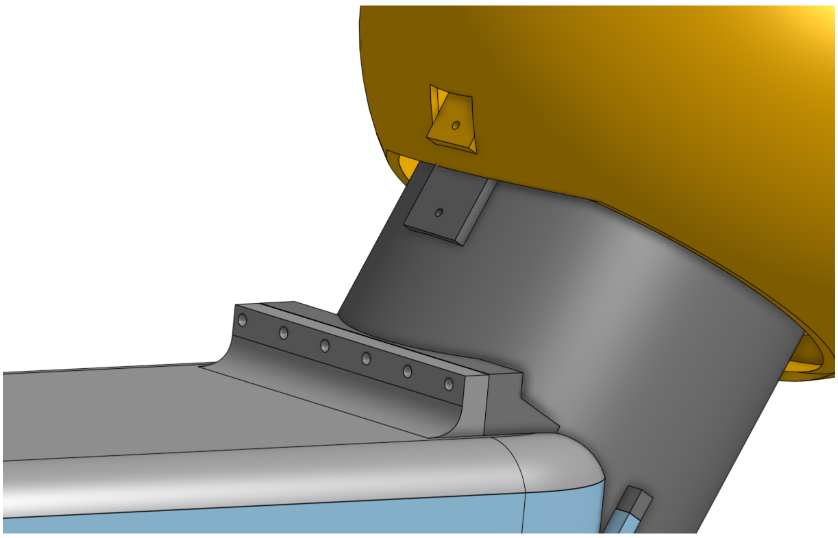

Figure 7: CAD design of the top lid and neck

Furthermore, the cat's ears had to be actionable : the final design choice was to have them be a separate piece, controlled by a servo motor. These servo motors were fixed into a specially designed piece that was attached to the head. Finally, the head contains several elements that need to be assembled, such as the neck servo motor, the ear pieces, and eventually an LCD screen to display the robot's face. To make sure the assembly of the head would be possible, the head needed to have a big enough opening. The solution for this was to have the head be split in two parts (rear and front parts) that are attached by a screwing mechanism.

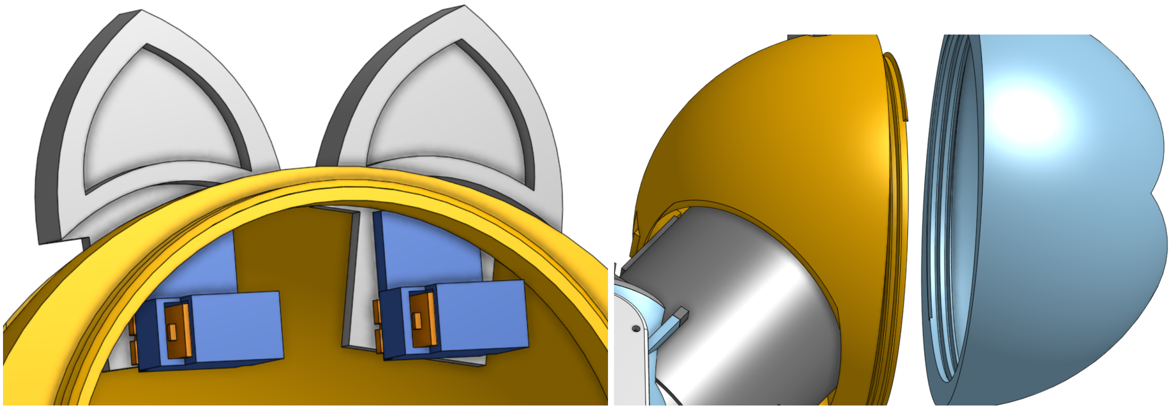

Figure 8: CAD designs for the ear parts and the head parts

2.2.6 Final design and price

Once the design was done, the pieces were 3D printed and progressively assembled to make the robot cat.

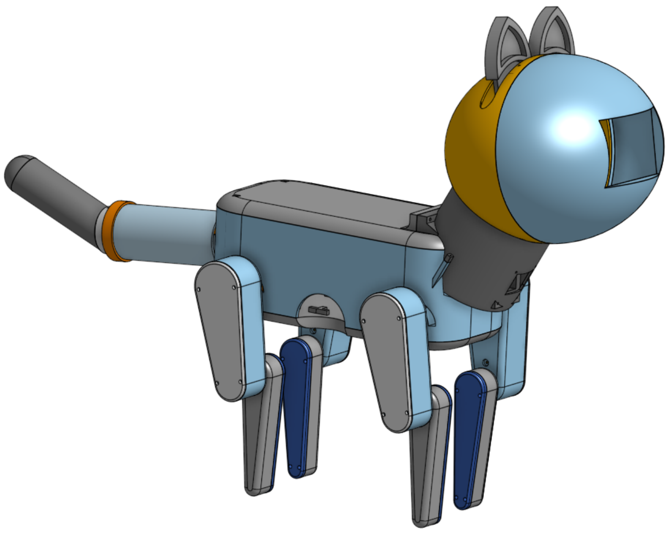

Figure 9: Full CAD design of the tabletop robot

To ensure the final product's affordability, the price of the necessary material was calculated :

Component	Quantity	Price per piece (in €)	Total cost
Ear	2	0.31	0.62
Ear servomotor holder	2	0.16	0.32
Head (back part)	1	3.98	3.98
Head (front part)	1	4.85	4.85
Lower leg	4	0.50	2.00
Lower leg lid	4	0.22	0.88
Lower tail	1	0.83	0.83
Lower tail lid	1	0.12	0.12
Main body	1	3.59	3.59
Main body bottom lid	1	2.75	2.75
Main body top lid	1	2.46	2.46
Neck	1	2.18	2.18
Servomotor support	22	0.013	0.28
Tail/body junction	1	0.11	0.11
Upper leg	4	0.87	3.48
Upper leg lid	4	0.28	1.13
Upper tail	1	0.89	0.89
Upper tail lid	1	0.20	0.20

Table 1: Components list with quantities and costs

The total printing cost amounts to 30.67€. This confirms the desired affordability of the robot.

Additional remarks:

- The pieces are printed using PLA
- The prices indicated above are calculated by adding the maximum amount of support material to the pieces when printing, and by considering the PLA price to be 25€/kg

2.3 Programming

The robot was not designed to be able to walk, but it was designed to be able to shift into different positions relatively quickly. As the previous joint diagram illustrated, the choice was made to have every joint be controlled by servo motors.

2.3.1 Electronic components

To action the robot, a Raspberry Pi 4 was used, fitted with Ubuntu 24.04. This project uses the Adafruit_CircuitPython_ServoKit Library to control the servomotors.To use this library on the Raspberry Pi, a virtual environment needs to be activated. Every time the Raspberry Pi is activated, the following command needed to be written in the terminal:

```
source env/bin/activate
```

The robot has 13 servo motors it needs to action simultaneously : to make this process easier, a PCA9685 Servo Driver with the capacity to control 16 servo motors at once was connected to the Raspberry Pi 4.

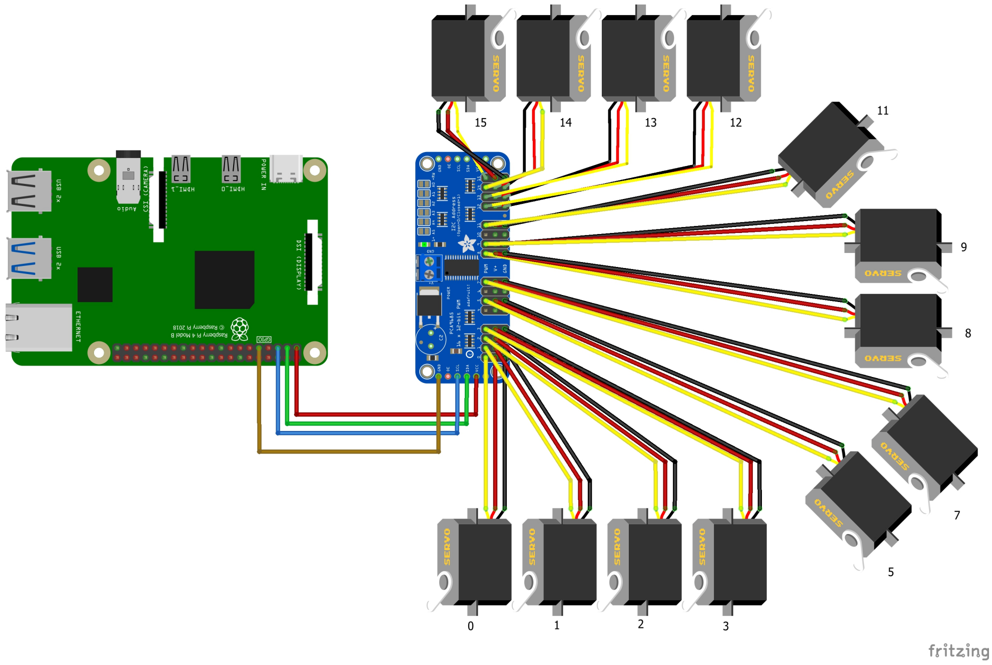

Figure 10: Circuit schematic of the tabletop robot

To be able to track the movements of the user while preserving their privacy, a Time of Flight Arducam camera is fitted to the neck of the robot. This camera emits modulated lights and uses the time it takes for the said lights to be reflected back to measure the distance info of any given object.

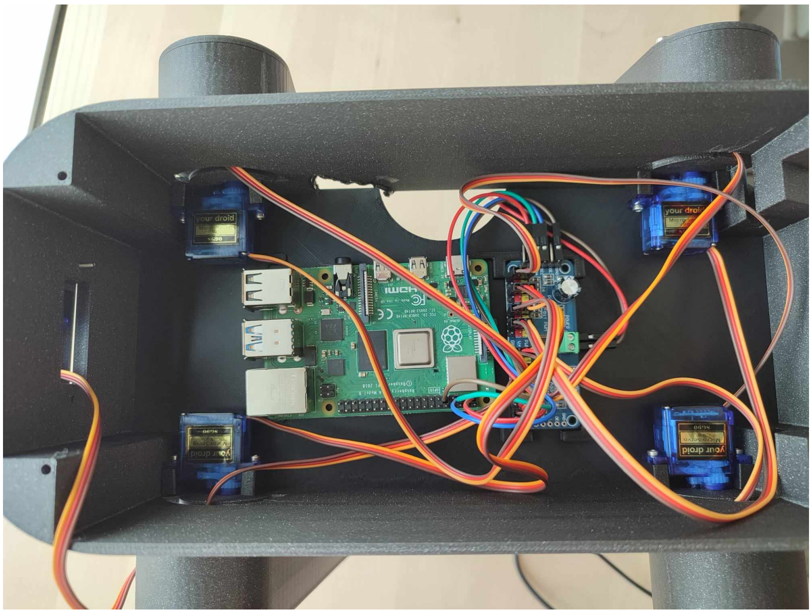

Figure 11: Picture of the robot's circuit showing the Raspberry Pi and Servo Driver

2.3.2 Choice of specific robot positions

As previously mentioned, the robot was designed to have a certain amount of set positions that it would circle through during the day depending on the user's behavior. After studying cat body language, three initial positions were kept. The original idea was to add an LCD screen that would show the robot's facial expressions depending on its conversation with the user : the delivery of the screen happening after the end of the internship, the screen was replaced with a template expression drawn on paper. The three positions are :

1. Laying position

   The robot spends its idle time in this position: while the user is working, it remains lying down without moving.

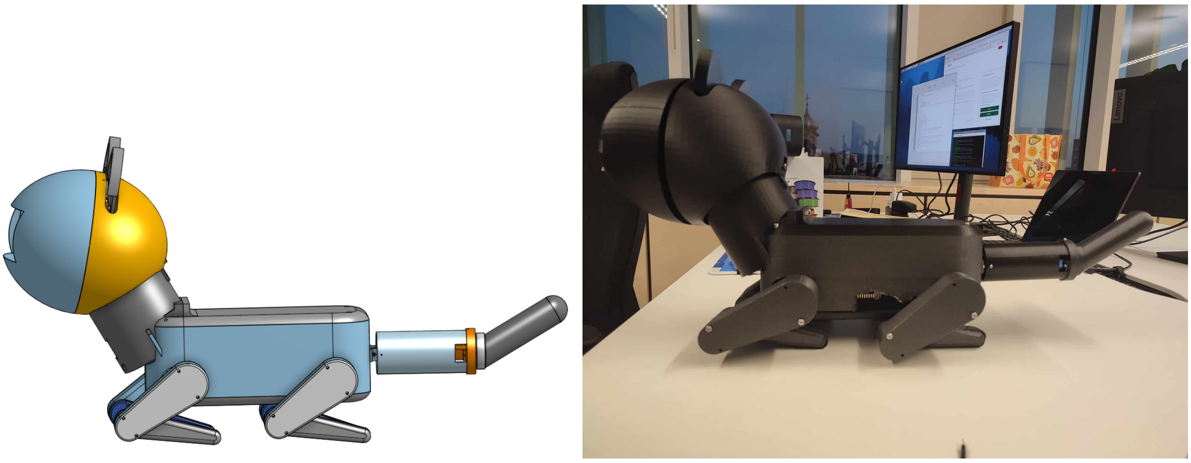

Figure 12: Comparison between the "laying down" position in Onshape and in real life

2. Sitting position

   The sitting position is a transitional one : to encourage the user to move by imitation, the robot slowly starts to rise from its laying down position to a sitting one. This first movement draws the attention of the user, and eases them into the upcoming interaction with the robot, instead of getting surprised by it.

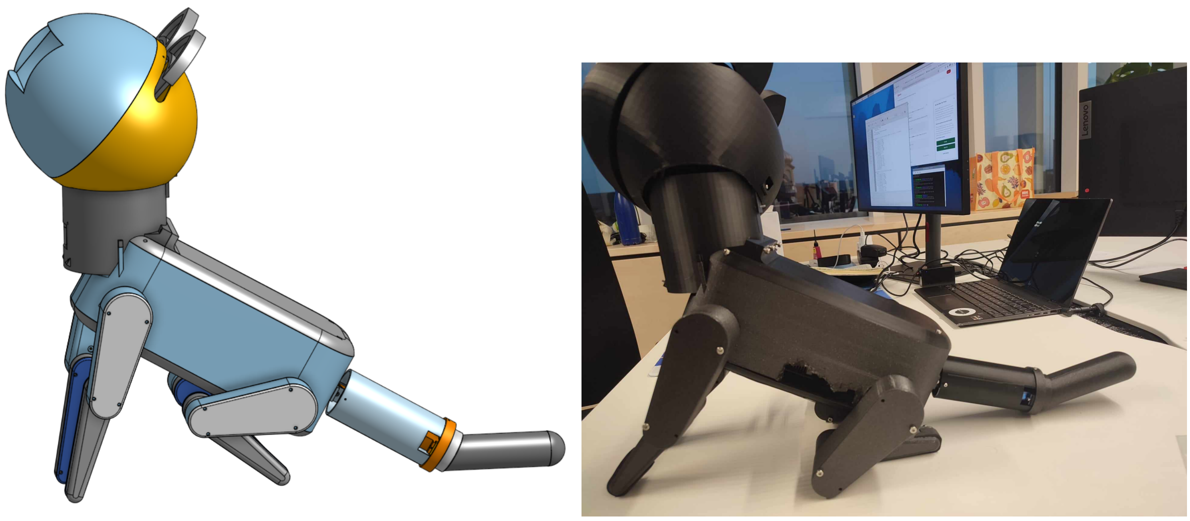

Figure 13: Comparison between the "sitting down" position in Onshape and in real life

3. Standing position

Finally, the robot reaches its standing position : once this position is reached, it will remain in the position for the entirety of its interaction with the user : in other words, until the user's break is over. Once the interaction is finished, it will revert back to the laying position.

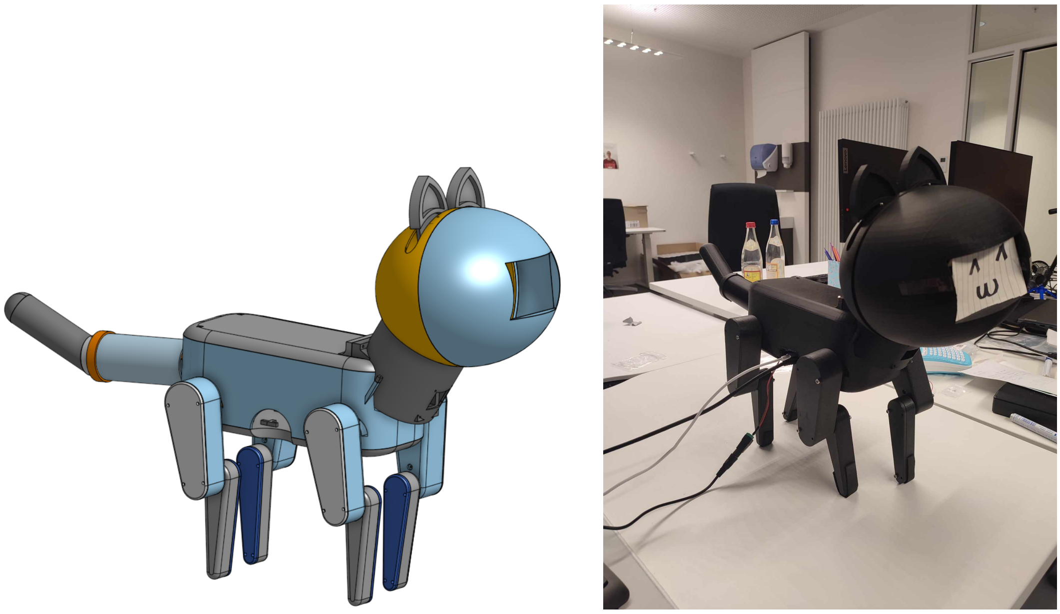

Figure 14: Comparison between the "standing up" position in Onshape and in real life

2.3.3 Code structure

This project was coded in Python. The three positions were all programmed in one python file. Several functions were implemented to achieve this :

- **angle_calibration():** No input, no output. Sets every servomotor successively to the 0°, 180°, and 90° positions. This helps to check that the servomotors have the desired 180° range and to see what the extreme values are.
- **individual_mapping(num, theta, speed):** Takes as arguments the number of the servomotor, its desired angle, and the speed (the lower the "speed" value, the faster the servomotor will reach its desired angle). It then moves the servomotor to the desired angle.
- **global_mapping():** Maps individually and initializes all servomotors to a start value (the current start values correspond to the standing position).
- **rounding(original_angle):** Takes an angle as an argument and returns its rounded-up value (or an arbitrary value of 90° if the original angle value is "None").
- **get_angles():** Returns a list of the current angle values for all servomotors (with rounded-up values).
- **random_position():** Assigns all servomotors a random angle between 0° and 180°.
- **standing(a0, a1, a2, a3, a5, a12, a13, a14, a15, speed):** Takes as arguments the angle values of the servomotors and a speed value. Changes the angle values to make the robot adopt a standing position. To make the servomotors faster, the speed value must be lowered (same as in *individual_mapping*).

- **sitting(a0, a1, a2, a3, a5, a12, a13, a14, a15, speed):** Takes as arguments the angle values of the servomotors and a speed value. Changes the angle values to make the robot adopt a sitting position. Similar to *standing*, the speed value should be lowered for faster movements.
- **laying(a0, a1, a2, a3, a5, a12, a13, a14, a15, speed):** Takes as arguments the angle values of the servomotors and a speed value. Changes the angle values to make the robot adopt a laying position. Similar to *standing*, the speed value should be lowered for faster movements.
- **tail_movement(a5, value):** Defines the tail movements.

2.4 Gitlab repository

To make sure the project could be easily picked up after the end of the internship, a Gitlab repository was developed.

3 Conclusion

The original goal of the internship was twofold: designing and programming the robot, and then testing it out to see its efficiency if there was enough time. The actual work accomplished between May and August ended up focusing mainly on the 3D design and programming of the robot : as of the end of the internship, the robot has been fully built and partially programmed, and thus is not yet operational to be tested. Moving forward, several things can be done to improve the robot:

- Several elements initially planned to be used for the robot were not implemented, such as the LCD screen and the speaker-microphone. The LCD screen was meant to display several pre-programmed facial expressions during interactions with the user, and the speaker-microphone was meant to allow the robot to listen to and be able to answer the user.
- Although the Arducam camera is set up and functional, the data it receives has not yet been utilised. The way forward would be to collect its data, analyse it, and adapt the current code to activate the different positions when certain types of user movements are detected.
- During the testing stage for the three positions currently programmed on the robot, there were some balance issues : the head and neck area was very heavy, which led to the robot leaning too forward during transitions between positions, and even some falls. Furthermore, the servo motors were sometimes not powerful enough to transition from "laying down" to the other two positions. One solution would be to find more powerful motors, or work on the head design to limit its weight.
- Once the code is fully implemented and the robot balanced and able to transition without problems between positions, the robot will need to be tested. The idea would be to spend several hours with it on the desk, and to see if its recommended break times are respected by the user.

The work during this internship was very autonomous, from the daily organisation to the general project outline. This led to a better awareness on how to organise a project from start to finish, and how to improve in time management. Furthermore, the internship helped become very competent in 3D designing and 3D printing and assembling of an entire robot.

The work at the SARAI lab is very different from the robotics courses at the ENSTA due to the social aspect : both the project and the other ongoing projects in the lab led to a better awareness of the variety of work that can be done in robotics. Social robotics and the focus on testing out robots also lead to learning more about experimental protocols, what factors one can evaluate during an exchange between a robot and a person.

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RAPPORT D'EVALUATION
ASSESSMENT REPORT

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Nom du stagiaire accueilli / *Name of intern* Alix AGNES

II - EVALUATION / *ASSESSMENT*

Veuillez attribuer une note, en encerclant la lettre appropriée, pour chacune des caractéristiques suivantes. Cette note devra se situer entre A **(très bien)** et F **(très faible)**
Please attribute a mark from A (excellent) to F (very weak).

MISSION / *TASK*

- La mission de départ a-t-elle été remplie ? *Was the initial contract carried out to your satisfaction?* — [X] B C D E F
- Manquait-il au stagiaire des connaissances ? *Was the intern lacking skills?* — ☐ oui/*yes* ☒ non/*no*

  Si oui, lesquelles ? / *If so, which skills?* ______

ESPRIT D'EQUIPE / *TEAM SPIRIT*

- Le stagiaire s'est-il bien intégré dans l'organisme d'accueil (disponible, sérieux, s'est adapté au travail en groupe) / *Did the intern easily integrate the host organisation? (flexible, conscientious, adapted to team work)* — [X] B C D E F

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* Alix integrated wonderfully in the group, adapted to our rules and customs and established great connections with all its members.

COMPORTEMENT AU TRAVAIL / *BEHAVIOUR TOWARDS WORK*

Le comportement du stagiaire était-il conforme à vos attentes (Ponctuel, ordonné, respectueux, soucieux de participer et d'acquérir de nouvelles connaissances) ?

Did the intern live up to expectations? (Punctual, methodical, responsive to management instructions, attentive to quality, concerned with acquiring new skills)?

☒ B C D E F

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* Alix showed competence, a great attitude to work and inclination for research (and openness to interdisciplinary research!) and autonomy at the level of a PhD student.

INITIATIVE – AUTONOMIE / *INITIATIVE – AUTONOMY*

Le stagiaire s'est –il rapidement adapté à de nouvelles situations ? ☒ B C D E F
(Proposition de solutions aux problèmes rencontrés, autonomie dans le travail, etc.)

Did the intern adapt well to new situations? ☒ B C D E F
(eg. suggested solutions to problems encountered, demonstrated autonomy in his/her job, etc.)

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* Developing a full robot prototype is a very open-ended and challenging task. Alix tackled all issues with great autonomy, initiative and perseverance.

CULTUREL – COMMUNICATION / *CULTURAL – COMMUNICATION*

Le stagiaire était-il ouvert, d'une manière générale, à la communication ? ☒ B C D E F
Was the intern open to listening and expressing himself /herself?

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* My group includes people from a variety of nationalities and cultures. Alix had positive interactions with everyone.

OPINION GLOBALE / *OVERALL ASSESSMENT*

❖ La valeur technique du stagiaire était : ☒ B C D E F
Please evaluate the technical skills of the intern:

III - PARTENARIAT FUTUR / *FUTURE PARTNERSHIP*

❖ Etes-vous prêt à accueillir un autre stagiaire l'an prochain ?
Would you be willing to host another intern next year? ☒ oui/*yes* ☐ non/*no*

Fait à ______, le ______
In Karlsruhe, DE, on 17.09.2024

Signature Entreprise
Company stamp

Signature stagiaire
Intern's signature

Merci pour votre coopération
We thank you very much for your cooperation