ROBOTICS AND MECHATRONICS

A robotic social actor for persuasive Human-Robot Interactions

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MSc Report

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Summary

The development of persuasive functionalities in social robots is a strategy aimed to increase the cooperation willingness of people with the robot, resulting in a better Human-Robot Interaction. Given this, it can be argued that efficiently influencing people behaviour is an elemental capability for social robots designed to assist human users. However, most of HRI research rely on the anthropomorphism of the embodied agent to facilitate its communication capabilities by using the limbs and the face. Due to this, there is an unexplored potential regarding the persuasive power of non-anthropomorphic robots with minimalistic designs.

This project explores the persuasive potential of non-humanoid robots by developing a desk light shaped 5 DOF robot arm to be used as a persuasive social actor. The robot was given behavioural characteristics such as emulated emotions and expressions intended to influence the behaviour of a human being. To achieve this, the RaM HRI Toolkit with Heterogeneous Multilevel Multimodal Mixing is used as software framework and expanded for the persuasive social robot. The goal is to assess the communication intent and interpretation of its expressions using nonverbal cues such as proximity, gaze, posture, and gestures.

The undertaken analysis pointed out that it is crucial to rely on nonverbal communication like body language and colours to overcome the limitations of using a non-anthropomorphic design. Emotions such as happiness or sadness and intent cues like agreeing or disagreeing can be translated from the joint space motions of the human body into the robot sequences.

The resultant embodied agent is a portable, minimalistic and robust system which resembles a real desk lamp. The programmed sequences and the configuration of the actuators allow the robot behave expressively and naturally. The carried out HRI tests showed that the robot is capable of attracting the attention of people and communicating intent efficiently under controlled circumstances. Nevertheless, it was found that the most critical limitation lies in the non-anthropomorphism of the robot itself, as it increases the difficulty of the interpretation of the nonverbal cues.

This work contributes to the existing knowledge of HRI by providing an overview of the basic requirements for a non-anthropomorphic robot to become a persuasive social actor. As further work needs to be done in this matter, it is suggested to shape the robot's behaviour around a user model to guarantee the predictability and reliability of the embodied agent. Besides, it is recommended to improve the integrated vision system and incorporate capacitive sensors and microphones to make the social robot aware of its environment and help it to shape the course of the persuasive interaction.

Preface

Before doing this master, I was working for an automotive company as an automation and maintenance engineer. Dealing with robot faults, the production urgency, wrecked sensors and the people was my daily life. Don't get me wrong, I was so happy being a half 'godinez[1]' and a half field engineer. However, I was always looking forward to doing a master degree in my beloved Japan. After working for four and a half years, I had the opportunity to give a 360° turn to my life and challenge myself by leaving my comfort zone. I was afraid but I needed to do it.

I arrived at the Netherlands and started my Master in Electrical Engineering at the University of Twente. The Netherlands is definitively not Japan. Don't get me wrong again, the opportunity of studying at the UT appeared in front of me. It was "an offer I couldn't refuse". On January 2016 I was 'respawn' in Enschede afraid, alone and forsaken. It was exciting for somebody like me who was never abroad for more than ten days.

Was it easy? HELL NO! Would I do it again? HELL YEAH! I learned so many things, not all of them academic related but of life itself. I overcame my insecurities and took salsa dancing lessons and judo. I had the chance to travel around Europe to do some photography. I got drunk among awesome friends from different countries. I learned to use the iron, to cook and survive. Without noticing, the Netherlands became my second home.

I did miss my family and friends. I missed the food and the culture of my Mexico. Fortunately, I was so busy dealing with my courses that I had no time to be homesick. I was learning to live by myself at a fast rate, that my mind was always distracted by the next thing to do. Later, I was presented with this fantastic thesis project of Human-Robot Interaction. I always wanted to work in my own robot and have the freedom to put my creativity on it. This was the chance. This report is just a summary of all the crazy things I did to develop this project. It was super fun! I would like to thank you for taking some time to read my stuff. Enjoy the ride!

"I always claimed I became the Batman to fight crime.
That was a lie. I did it to overcome the fear." - Batman (Bruce Wayne)
Batman: The Cult by Jim Starlin & Bernie Wrightson

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Overwatch player, Batman enthusiast, photographer wannabe, Rock listener and salsa dancer.
He wants to rule the world with ninja-robots, mojitos and tequila.

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Enschede, March 2018.

[1] https://www.urbandictionary.com/define.php?term=godinez

Contents

1 Introduction

Social robots play an essential role in modern society due to their vast potential to assist people (Chidambaram et al., 2012) as utilitarian equipment and companions. Some of these roles may include being a teaching assistants for children (Shimada et al., 2012) or care companions for elder people (Klein and Cook, 2012). While performing a task, the social competences of robots are critical when dealing with humans as main interaction targets. A notable example of such skills is *persuasion*, as - stated by Chidambaram et al. (2012) - "the success of these robots [...] will rely largely on their ability to persuade people".

1.1 Context

The development of persuasive functionalities in social robots is a strategy aimed to increase the cooperation willingness of people with the robot, resulting in effective Human-Robot Interactions (HRI). A persuasive interaction occurs when at least two entities agree to communicate cooperatively to reach a goal (Bettinghaus, 1973). Therefore, it can be argued that efficiently influencing people behaviour is an elemental capability for social robots designed to assist human users.

Human-Robot Interactions differs from Human-Computer Interaction as the robot plays a physical role in the communication process which is distinctive in Human-Human Interactions (Zhao, 2006). This statement refers to the nonverbal communication that a robot could be capable of expressing using its actuators. Studies have shown that people tend to be more compliant with robot's suggestions when the embodied agent employs nonverbal cues (Chidambaram et al., 2012). Hence, the physical body of a robot may be strategically used to give persuasiveness to the communication process.

1.2 Goal & research questions

This project explores the persuasiveness potential of non-humanoid robots by developing a desk light shaped 5-DOF robotic arm intended to act as a persuasive social agent. Therefore, it is given behavioural characteristics such as emulated emotions and expressions. Before proceeding to evaluate the persuasiveness of the robot, it is of primary interest and importance to assess the communication intent and interpretation of its expressions.

Consequently, the research questions of this project are as follows:

- How can a non-humanoid robot become a persuasive social agent?
- Is the design and behaviour of the robot capable of attracting people's attention?
- How can a non-humanoid robot express emulated emotions using nonverbal communication only?
- To what extent can the robot communicate intent through nonverbal communication?

1.3 Approach

To answer the previous questions, the RAM HRI Toolkit with Heterogeneous Multilevel Multimodal Mixing (Davison et al., 2017) is expanded and applied to the robotic desk light as software framework. Besides, insights on persuasive communication theory, body language and colour psychology are used as background for this research to find the appropriate behaviour of the robot. Likewise, the limitations of the physical design like the lack of face or limbs are studied and tackled. Finally, the robot is subject to HRI tests to evaluate its intent-communication potential through the response of the people interacting with it.

1.4 Report outline

The second chapter of this report will examine the concept of Social Robotics, followed by a brief overview of the state of the art of robots as persuasive agents. Chapter three analyses the requirements and limitations of the DeskLight robot, along with the justification of its hardware and software design. The fourth chapter is concerned with the implementation of the robot and the HRI experiments. Chapter 5 presents the findings in the response of the people interacting with the developed robot. Finally, the last chapter proceeds with the discussion of the results, concluding with further suggestions for research.

2 Analysis

Robots performing for humans are not new in the field of robotics. A well-known example is the *animatronics*, such as the Tyrannosaurus Rex at the London's Natural History Museum (portrayed in Fig.2.1). These robots are designed to resemble and 'act' as a particular character. In contrast, a social robot not only performs for humans but also interacts with them to achieve a specific goal. As mentioned in the introduction, this chapter gives a brief description of Social Robots, followed by an overview of the work done so far in Persuasive Human-Robot interactions. Emphasis will be given to the communication capability of social robots, especially to the nonverbal interaction.

Figure 2.1: Animatronics T-Rex 'acting' for a human audience.

2.1 Robots as Social Actors using nonverbal communication

Robots are increasing their presence in more domestic applications (Taipale et al., 2015), however, not every robot operating in a non-industrial environment could be classified the same. According to Zhao (2006), a robot may be classified on the basis of its interaction target into *Industrial Robots* and *Social Robots*. An example of a domestic-industrial robot could be the Roomba vacuum cleaner (see Fig.2.2) by iRobot. Despite having a user interface to interact with a human being, the primary interaction targets of the Roomba are the floor to be cleaned and the objects lying around. On the other hand, the work of Anzalone et al. (2010), in which robots with different character were developed to assist humans (see Fig.2.3), is an example of social robotics.

A *Social Robot* is defined as an autonomous embodied agent engineered to interact with humans communicatively (Breazeal, 2003). From this definition, the words *communication* and *interaction* become essential terms. It is not intended to expand into such concepts as they are topics of more specialised fields like Psychology and Communication Science. Nonetheless, because robotics is often inspired by nature (Metta et al., 2010), the Human-Human interaction (HHI) process becomes the guidance for successful Human-Robot Interactions (HRI). This is shown in the work of Park et al. (2012), in which the law of attraction in HHI inspires the development of robots capable of mimicking different personality types.

Figure 2.2: Roomba cleaning the floor.
Source:
http://www.irobot.com/For-the-Home/Vacuuming/Roomba.aspx

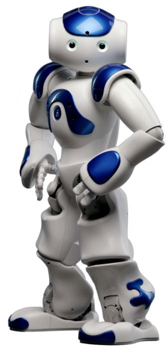


Figure 2.3: Robot Nao used by Anzalone et al. (2010).
Source:
http://www.ald.softbankrobotics.com

Any kind of *interaction* among two or more entities necessarily involves *communication*[1]. As defined by Bettinghaus (1973), "a communication situation exists whenever one person transmits a message that is received by another individual and is acted upon that individual". Hence, any HRI situation is a communication process between the robot and a person. This kind of interaction, same as any HHI, contains the four elements of communication: *Source, message, channel and receiver* (Bettinghaus, 1973), which are illustrated in the diagram of Fig.2.4.

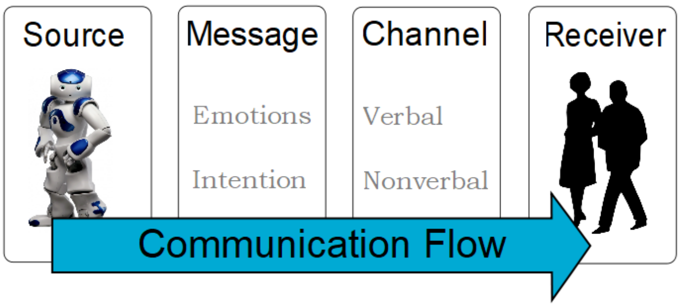


Figure 2.4: The four elements of communication.

The importance of communicative capabilities in social robots can be exemplified with the work of Anzalone et al. (2015), which mentions how humans may struggle to decipher the message coming from the robot if it lacks communication abilities. Due to this problem, there is a tendency in studying the *communication channels* on HRI. In other words, how a robot could deliver a message in such a way humans can evidently anticipate intention and interpret emulated emotions. An example is the contributions of Busch et al. (2017) and Dragan et al. (2015), which conclude that the response of people interacting with robots is improved when the embodied agent has a reliable nonverbal communication through motion.

As indicated in the previous chapter, the robot developed for this project relies only on non-verbal cues to communicate intention and emulated emotions. The justification of this design is not a matter of this chapter. However, it is essential to mention the influence of nonverbal communication in social robots. The course of social interaction is driven by the intelligence

[1] Meaning of *Interaction* according to the Cambridge Dictionary: https://dictionary.cambridge.org/dictionary/english/interaction [Accessed: 23/01/2018]

levels of the individuals engaging in such interactions. The perceived intelligence in a social robot is correlated with its nonverbal cues such as eye gaze, nodding, upright posture, along with other gestures and expressions (Murphy, 2007). This relation can be seen in a recent study by Kennedy et al. (2017), which showed how nonverbal immediacy in social robots might facilitate the learning process of children interacting with them.

Expressing emotions also influence the perception of intelligence, as emotion plays a role in human cognition (Megill, 2014). According to Masahiro (as cited by Marinetti et al. (2011)), the capability of communicating emotions is essential for a social interactive agent. Consequently, a robot should be capable of communicating emotions when engaging in HRI. However, a robot lacks emotions per se. Given this, any social robot should be designed to emulate emotions that could be evidently interpreted by humans. The following section of this chapter explores the expression of emotions via nonverbal communication.

2.2 Expressing emotions through nonverbal cues

Luxo Jr. is the name of an animated short film produced by Pixar Animated Studios[2] in 1986. This is a story of two desk lamps interacting with a ball. The attractiveness of this film is the expressiveness of these non-humanoid characters who employ only nonverbal communication. Happiness, excitement, sadness, curiosity and other emotions are communicated by the characters, despite not having face or limbs. This competence suggests that the physical shape does not influence the expressiveness of a robot, as - quoting Hoffman (2013) from a TEDx conference - "emotions are not in the 'look', but in the motion, the timing how the thing moves".

Figure 2.5: Poster for Luxo Jr.
Source:
https://www.pixar.com/luxo-jr/#luxo-jr-1

Figure 2.6: Characters showing curiosity.
Source:
https://www.pixar.com/luxo-jr/#luxo-jr-1

The previous is demonstrated in the work of Beck et al. (2011) by employing a robot showing different head positions to display emotions identifiable by children. The mentioned study concludes that the lack of face does not impede emulating emotions (Beck et al., 2011). The same can be assumed for the lack of limbs, taking the film *Luxo Jr.* as an example. Then, it is suggested that low and non-anthropomorphic robots have good chances to communicate emotions and intentions relying only on nonverbal cues if their motions are well-designed (Hoffman and Ju, 2014).

[2]An American computer animated film studio: https://www.pixar.com/

Beck et al. (2011) suggest the use of *postures* and *movements* to assess displaying emotions in a Social Robot. For instance, the head positions of the desk lamps in *Luxo Jr.* are postures that mimic the human body language. The same holds for their movements, such as: nodding to show agreement; shaking the head to disagree; or moving the whole body as a symbol of joy. These postures and movements were applied to the *eyePi*, developed by Oosterkamp (2015). The eyePi (shown in Fig.2.7) is a non-anthropomorphic robot which emulates emotions aided by nonverbal cues.

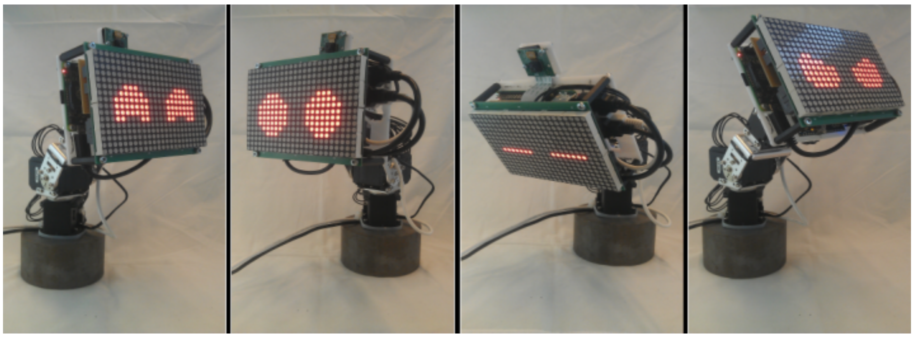


Figure 2.7: The eyePi robot developed by Oosterkamp (2015).

Nonetheless, body language is not the only way to nonverbally communicate emotions and intention. Based on the theory of Color Psychology, Elliot (2015) (p.401) states that "color may serve either as an emotion elicitor that creates an emotional impact on the viewer or as an emotion messenger [...]". Table 2.1 gives a summary of the emotions that may be evoked by colours, according to Keskar (2010). As the usage of postures/movements and the display of colours are not mutually exclusive, these techniques could be combined to improve the nonverbal communication of the social robot.

Color	Meanings or representation	R	G	B
White	Purity, neutrality, peace.	*255*	*255*	*255*
Red	Passion, danger, love, anger	*255*	*0*	*0*
Orange	Enthusiasm, happiness, energy	*255*	*128*	*0*
Yellow	Joy, happiness, optimism, danger	*255*	*255*	*0*
Green	Nature, life, harmony, creativity	*0*	*255*	*0*
Blue	Depression, coldness, conservatism	*0*	*0*	*255*
Purple	Wisdom, arrogance, pride.	*128*	*0*	*255*
Pink	Admiration, sympathy, joy.	*255*	*153*	*255*

Table 2.1: Summary of colors and their meanings (Keskar, 2010).

Expressing emotions to other individuals can influence how they react to us (Marinetti et al., 2011). Hence, the emulated emotions of the robot may be applied as a communication tool to persuade people. The next section addresses the concept of persuasive communication and the state of the art of persuasive social robots.

2.3 Robots as persuasive agents

Nowadays, people's decision making and judgment are influenced continuously by computerised systems. A simple example of such technologies is the fitness and productivity applications which encourage the user to reach their goals through suggestions and rewards. These 'apps' or any other interactive computer system intentionally designed to change people's behaviour are known as *Persuasive Technology* (Fogg, 2002).

As defined by G.R. Miller in 1980 (cited by Stiff and Mongeau (2003)), *persuasive communication* is "any message that is intended to shape, reinforce, or change the response of another or others". Due to persuasion implies communication (Bettinghaus, 1973), Persuasive Technology relies on the communication channel to successfully deliver the message to its target. However, this technology must first attract the attention towards itself to begin any communication situation.

It is argued that a robot would be more interesting to pay attention to, than a program on a screen because - quoting Hoffman (2013) - "we can't ignore physical things moving around". In terms of persuasiveness, a more attractive *source* has an advantage over its less interesting counterparts (Stiff and Mongeau, 2003). In other words, the more attractive a technology is, the more persuasive power it will have (Fogg, 2002). Nonetheless, engineering a robot that can steer human behaviour is a big challenge for robotics (Ham et al., 2011), starting with the physical design of the embodied agent.

In 1970, Masahiro Mori introduced the concept of *Uncanny Valley*. This term refers to the response that people tend to have toward a robot which physical design resembles so much to a human being, but it is still far from perfect human likeness. As pictured in Fig.2.8, the uncanny resemblance of a robot to a human shape notably decreases the affinity or familiarity people have with that robot. This negative effect is worsened when motion is present (Mori et al., 2012). This consequence is exemplified by the work of Walters et al. (2008), which concludes that people will be inevitably disappointed if the robot's behaviour is below to the expected given its overall appearance. Considering that the success of a persuasive interaction is influenced by the affinity people have with the *source*, the design of any persuasive social robot shall avoid the uncanny valley.

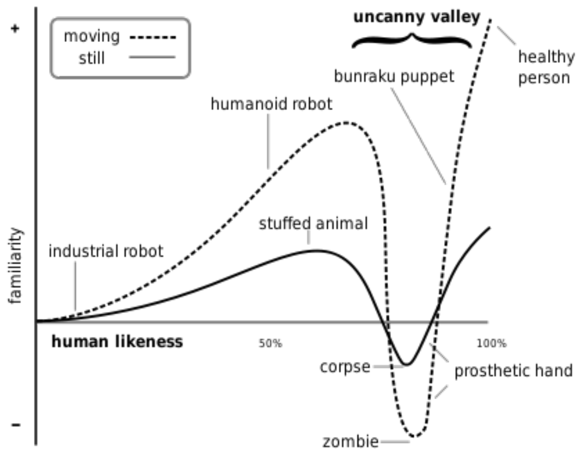


Figure 2.8: Graphic representation of the Uncanny Valley by Mori et al. (2012).

As indicated above, the behaviour of the robot also influences the affinity of people toward it. This is the case of the Aldebaran Nao robot used by Stanton and Stevens (2017) while studying the role of the *gaze* in persuasive HRI. In the mentioned research, the Nao robot moved its head to stare at a human subject when suggesting him/her to change an answer. The test showed that the use of gaze in a social robot impacts the affinity for it and can increase the cooperation willingness of the human participant (Stanton and Stevens, 2017).

Another example of persuasive strategies applied to social robots is the research of Ham et al. (2015), which mentions the importance of gazing and gesturing to achieve persuasiveness. The cited study consisted of a humanoid robot telling a persuasive story while using gestures and looking to the people. It concludes that using gestures is not enough to achieve persuasiveness if the robot's behaviour is not accompanied with gazing (Ham et al., 2015). Other researches studying the compliance of people toward robots which use nonverbal communication are the works of Chidambaram et al. (2012) and Looije et al. (2010). The common denominator in the mentioned studies is the use of *posture, gaze, expressions* and *proximity* to persuade.

Most researchers investigating *Persuasive Human-Robot Interactions* have utilised high-anthropomorphic robots in their experiments. The advantage of this kind of robots is the possibility to employ their limbs and faces to establish nonverbal communication as a human being would do. However, this approach relies on the robot's likeness to a human shape to ensure positive affinity toward it. The reviewed literature suggests that there is an unexplored potential regarding the persuasiveness of non-anthropomorphic robots with minimalistic designs. The film *Luxo Jr.* is a good example that an agent with a minimalistic design is capable of communicating feelings and intent.

An example of non-anthropomorphic robots collaborating with humans is the *AUR Robot Desk Lamp*[3] by Guy Hoffman, portrayed in Fig.2.9. This robot was designed to communicate with a human partner without using human-like features. A similar concept is explored with the *Poppy Ergo Jr. robot*, shown in 2.10, which is used for educational activities[4]. These two examples exploit the non-anthropomorphism of the agent to avoid the *Uncanny Valley* but compensating with nonverbal language to be communicative.

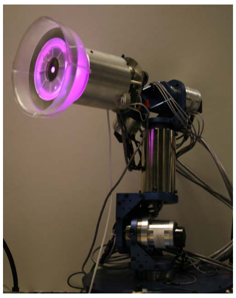


Figure 2.9: Hoffman's AUR robot.
Source:
http://robotic.media.mit.edu/portfolio/aur/

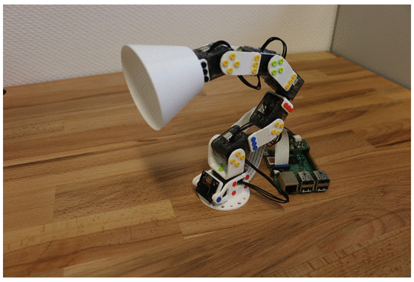


Figure 2.10: Poppy Ergo Jr © Inria.
Source:
http://robotic.media.mit.edu/portfolio/aur/

To conclude this chapter, one question that needs to be asked is: To which extent can a non-anthropomorphic robot become a persuasive social actor? This chapter has analyzed the characteristics of social robots and HRI, focusing on the nonverbal communication a robot may employ to express emulated emotions and communicate intent as a strategy to achieve persuasiveness. The next part of this report will address the hardware and software requirements for a minimalistic robot capable of engaging in Persuasive Human-Robot Interactions.

[3] http://guyhoffman.com/aur-robotic-desk-lamp/
[4] https://www.poppy-education.org/

3 Requirements

As a result of the previous analysis, the diagram in Fig.3.1 summarises the behaviour and appearance requirements a persuasive social robot shall fulfil. The robot's body - whatever shape it is - can be exploited to emulate emotions and express intent using body language and colour cues. Regarding its appearance, it might be crucial to avoid the *Uncanny Valley* by the non/low-anthropomorphism or full-anthropomorphism of the agent. This chapter explains and justifies the chosen design of the robot according to the mentioned requirements. Later, based on the behavioural needs, the hardware and software selections will be discussed.

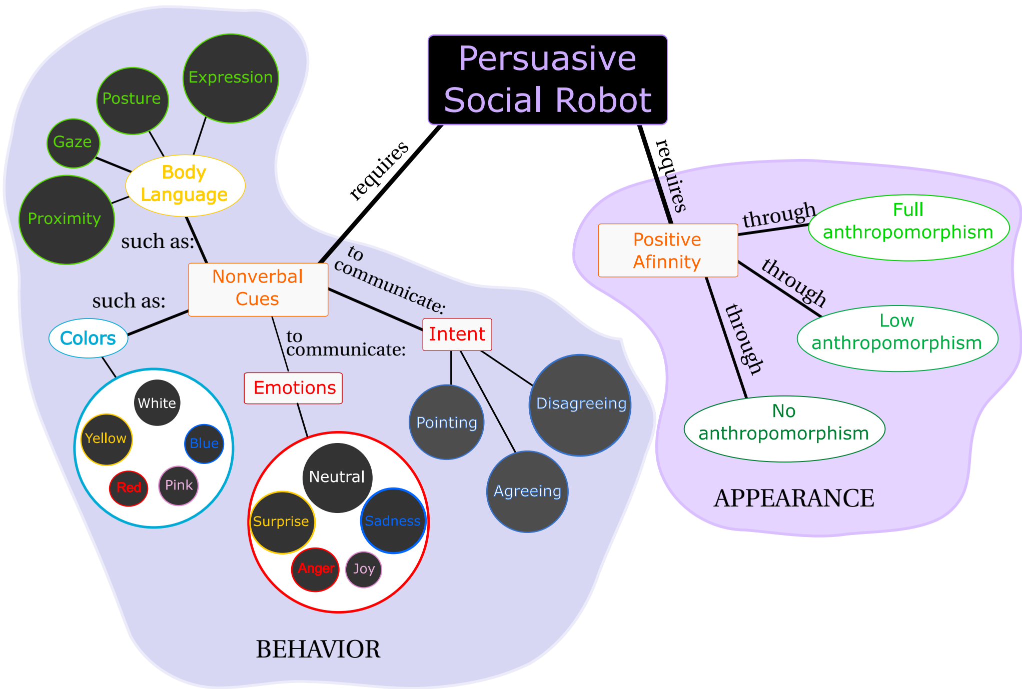


Figure 3.1: Summary mind map of the behavioural and physical aspect requirements of a Persuasive Social Robot.

3.1 Robot configuration

The full-anthropomorphism of a robot highly increases the hardware and software requirements as it must fully resemble a human being in: how it looks; response time, and behaviour. This is because the anthropomorphism of the agent increases the expectation of the people interacting with it. This phenomenon may backfire as any behavioural imperfection of the robot will provoke uncomfortable experiences (Marinetti et al., 2011). In the other hand, a low or non-anthropomorphic robot could have a minimalistic hardware design and a less complex software as is not expected from it to behave as a fully healthy person.

An example of minimalistic design is given by Zaga et al. (2017), who concluded that it is possible to communicate social engagement and task-related information with 1-DOF robot movements. However, it is still unknown to what extent such minimal solution limits the expressiveness of an embodied agent. As persuasiveness is a more complex interaction situation, the communication effectiveness of the robot should not be compromised by its design.

Different robot configurations with increasing number of degrees of freedom are shown in Fig.3.2; from 1 axis solutions as proposed by Zaga et al. (2017), to more complex shapes as the *Aldebaran Nao*. The 3-axis *eyePi*, developed by Oosterkamp (2015), is a matter of interest as it is the lowest DOF robot with embedded social capabilities. Other proposals with greater number of axis or limbs, such as *Nao*, become more anthropomorphic. Both the *eyePi* and *Nao* rely on their faces for gazing and expressing emotions, which is undesired in this project. Due to this, the optimal solution requires more than three but no more than six axes, as six are enough to reach every point of the space. Inspired by the movie *Luxo Jr.*, **a 5-DOF robot arm solution is proposed**. A similar concept is the pneumatic desk lamp developed by E. Dertien[1], portrayed in Fig.3.3. It is believed that the design of an inanimate object may have a positive impact in the affinity of the people toward the robot as is not expected of a desk lamp to express emotions nor intent.

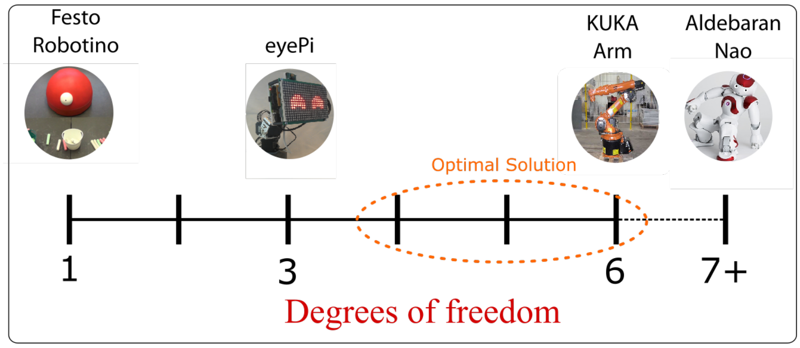


Figure 3.2: Different DOF robot designs. From left to right: 1 DOF - Festo Robotino used in the research of Zaga et al. (2017); 3 DOF- eyePi social robot developed by Oosterkamp (2015); 6 DOF- Kuka industrial arm robot (Source: https://www.robotshop.com/); 7+ DOF- Aldebaran Nao used in most HRI researches (Source: http://www.ald.softbankrobotics.com.)

Figure 3.3: 'pix', interactive pneumatic desklight, art project by E.Dertien, on show during Gogbot 2009.

Fig.3.4 pictures the chosen robot configuration, which shows the skeleton representation of each joint along the Pixar's desk lamp design as an example. Assuming Joint 1 is at zero position as in the figure, the Joints 2, 3 and 5 rotate in the x-axis. Joint 4 rotates in z-axis with respect to the frame of Joint 3. Unlike the characters in the animated movie, the robot will not move from its position with respect to the ground. However, this displacement restriction is not expected to affect the expressiveness of the robot negatively. To achieve this, a proper hardware and software discussion is done in the following section of this chapter.

[1] http://retrointerfacing.edwindertien.nl/

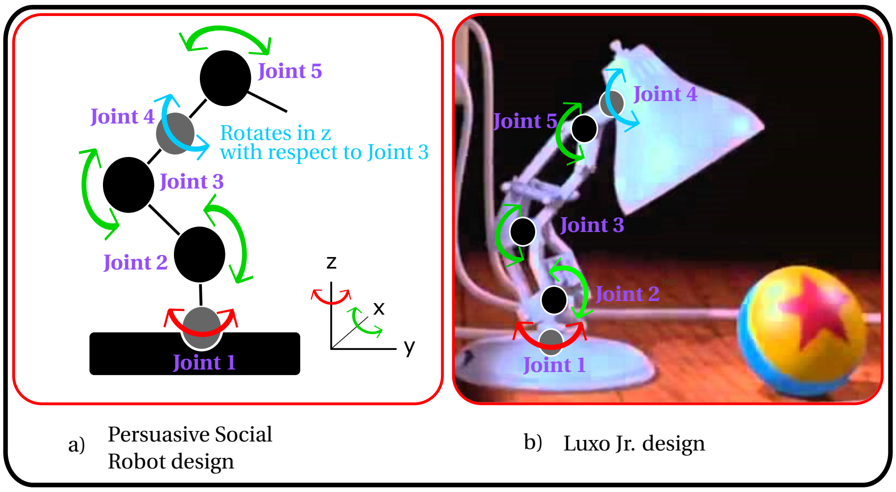


Figure 3.4: The persuasive social robot design based on Luxo Jr.
Luxo Jr. and ball image source:
https://disexplorers.com/2017/04/03/luxo-jr-ball/

3.2 Hardware and Software selection

As mentioned in this report, it was of main interest to achieve a minimalistic design, not only in the appearance of the robot but also in its construction. First, the mechanical components will be described, followed by the control elements needed to achieve the expected behaviour of the robot. Later, insights of the chosen software will be given.

3.2.1 Physical components

Taking advantage of the All-in-one design of the DYNAMIXEL[2] actuators, these servomotors were selected along with the brackets of the same manufacturer. The chosen motors have shown good performance in other social robot projects such as the *eyePi*. Similarly, the main computer chosen for this project is the Raspberry Pi platform. To focus the people's attention to the robot, it was decided to discretely enclose all the electronics in an aluminium box that also works as a base for the desk light.

As a social robot, the desk light requires input and output peripherals to communicate with humans. The Raspberry Pi embedded camera was implemented as input to give the robot a real-time interaction with the user and some autonomy. The MIDI controller panel was chosen as an input device to puppeteer the robot with acceptable precision and smooth movements. This choice was done because the MIDI contains enough analogue inputs to control each of the five joints and other features separately. As an output, a 16-LED ring was selected to show different light colours as emotions according to Table 2.1.

The diagram in Fig.3.5 shows the overall hardware selection of the persuasive social robot, including the connexion among the peripherals. The communication network applied to drive the actuators is RS485 expecting to obtain the same good results given by the *PIRATE* project by Dertien (2014) and the *eyePi* which used the same protocol. A USB to RS485 converter was used to simplify the data transfer between the motors and the main computer. The MIDI controller is connected directly to the Raspberry Pi via USB, as well as an Arduino micro used

[2] http://www.robotis.us/dynamixel/

to control the LED ring. The complete list of components is listed in Appendix A.

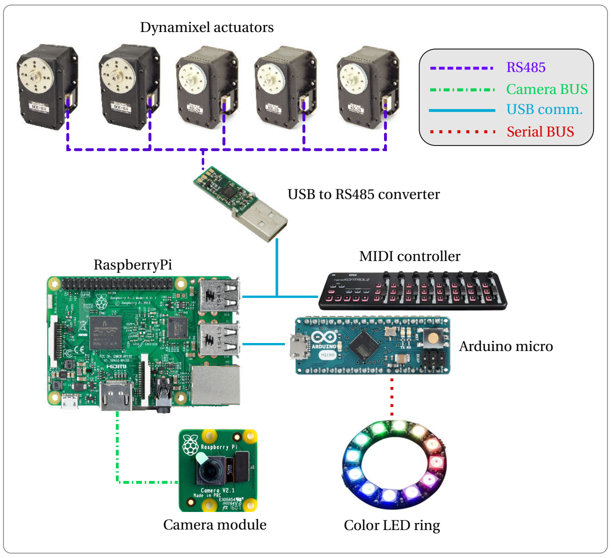


Figure 3.5: Electronic components of the persuasive social robot.

3.2.2 Control software

As previously stated, the software framework chosen to control the persuasive social robot is the *RaM Human-Robot Interaction Toolkit with Heterogeneous Multilevel Multimodal Mixing* developed by Oosterkamp (2015) and later improved by van de Vijver (2016). The available toolkit has been implemented in *Robot Operating System (ROS)* and already contains the essential features of a social robot and has been successfully applied to the *eyePi* into its latest iteration. However, the software needed to be expanded to give more expressiveness and persuasive capabilities to the embodied agent.

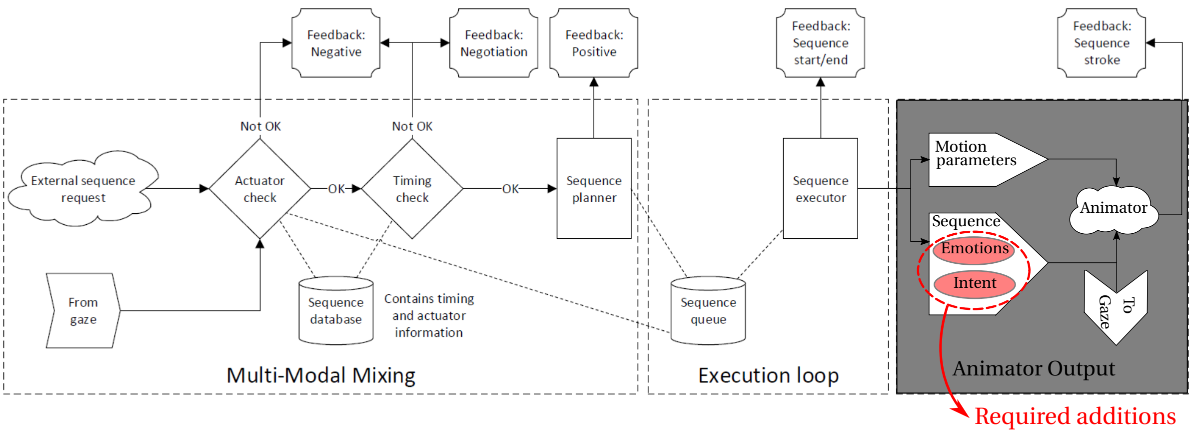


Figure 3.6: HMMM behavior mixing (van de Vijver, 2016) with the required emulated emotions and intent sequences.

Starting from the latest version of the HRI toolkit installed in the *eyePi*, two additional joints needed to be added as the framework was coded for only 3 DOF. The pre-programmed emotion sequences required to be modified to increase the expressiveness of the movements in the absence of facial expressions. Besides, a series of 'persuasive' sequences needed to be programmed to give the robot means to express intent such as agreement or disagreement.

The gaze also required to be merged with the *'emotion'* state of the robot to give a more realistic experience to the interaction. The diagram in Fig.3.6 shows the needed expansion of the *Animator Output* by improving the Emotion and the addition of the Intent sequences. For completion, the HMMM concept refers to a feature inside the framework that allows a robot to interact with multiple users through gaze, allowing it to prescind from a puppeteer (Davison et al., 2017). More details about the *Multi-Modal Mixing* and the *Execution Loop* are given by van de Vijver (2016).

Another contribution of the RaM HRI toolkit is the integration of the Arousal and Valence model to determine the robot's emotional state, which is shown in Fig.3.7. The valence is related to the pleasure-displeasure of the emotion, while the arousal refers to its energy level (Yik et al., 2011). The six basic emotions described in the figure determine the behaviour of the robot as in Fig.2.7. Unlike the *eyePi*, the persuasive social robot required convincing body language sequences to represent each of the emotions of the Valence-Arousal circle. As nonverbal cues are the only communication channel of the robot, high priority was given to its movements and colours displayed on the LED ring.

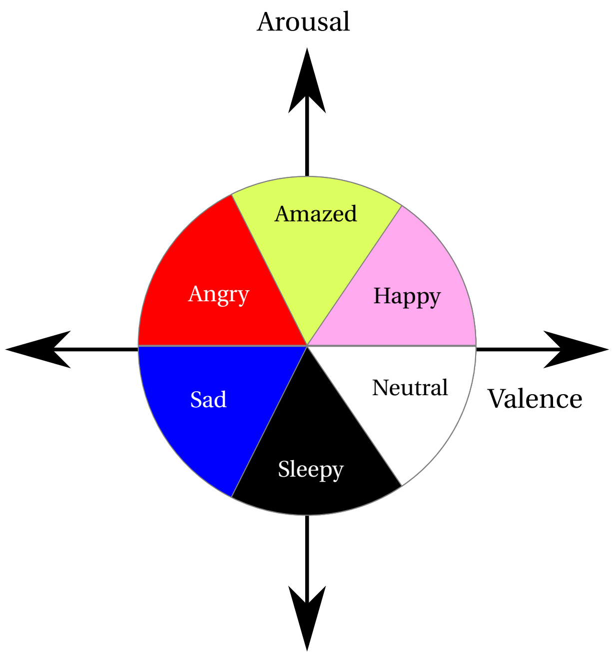


Figure 3.7: Valence-Arousal circle of emotions mapped into the robot.

3.2.3 Robot movement strategy

This section discusses the motion strategy of the robot based on its behavioural requirements. Given the diagram in Fig.3.8, forward or inverse kinematics could be used to program each of the movement of the robot just as it is done in the game programming and 3D animation industry. However, it is not required for the movements to be precise or repeatable given the nature of the social robot's function and its non-humanoid shape. Also, it was intended to keep the positions as simple but expressive as possible. Thus, it is proposed to use preprogrammed individual joint angles to animate the robot in a believable way as some bits of nonverbal communication can be translated from the human body joint space.

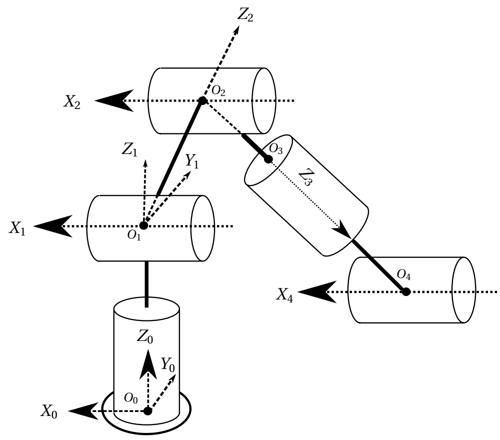


Figure 3.8: Kinematic scheme of the 5 DOF robot arm.

The position of the end effector is not the only interest in the robot's motion. As it is essential to take in mind the expectation of the people interacting with the agent, the angular position of each of the joints needs to be carefully chosen. This strategy was taken to avoid any bizarre or strange movement that could provoke uncomfortable experiences to the users. As the robot has the shape of a desk lamp, its movements should not deviate too much from the ones that could be expected by a user when the concept 'desk lamp' comes to mind. Hence, for each of the emulated emotions, the joint positions were chosen as shown in Fig.3.9. The kinematic chain of the robot was configured to simulate those expressions by using generic human body postures as models.

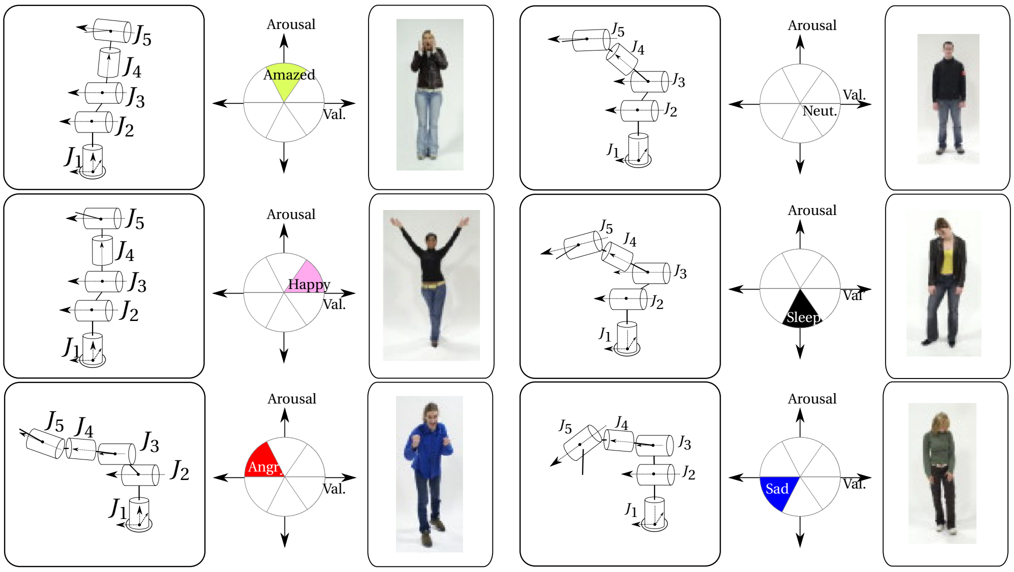


Figure 3.9: Positions of the kinematic chain emulating emotional human postures.
Human postures credit and source: J. Soames
http://santoshabodywork.com/2013/05/22/posture-vs-alignment-what-do-they-mean-who-cares-i-do/

3.2.4 System timing and constraints

A robot with socially believable behaviour should be designed to simulate spontaneous human interactions (Esposito and Jain, 2016). The previous claim not only refers to the communication skills of the agent but also to the timing of its actions. In other words, how can the social robot meet the timing requirements of the interaction with a human? During a HHI, a delay in the response from any of the involved sources could make the communication process uncomfortable and less effective. Some of the challenges of delayed voice communication may include confusion of sequence, slow response and reduction of the situational awareness (Love and Reagan, 2013). It could be expected from these problems to arise also when the communication is only nonverbal. Given this, the responsiveness of the persuasive social robot is critical for the effectiveness of the interaction.

The behaviour of the robot must adapt on-the-fly either by a scene analyser platform (Davison et al., 2017) or by a skilled puppeteer. Both the scene analyser software and the puppeteer operate in soft real-time as some execution deadlines may be missed. This timing allowance holds as long as the response delay does not degrade the communication process. The diagram in Fig.3.10 displays the behaviour generation for a persuasive social agent. The scope of this project is on the low-level control of the robot, focusing on the expressiveness of its postures and movements. However, any software optimisation on the timing would improve the response of the robot upon any change of the interaction.

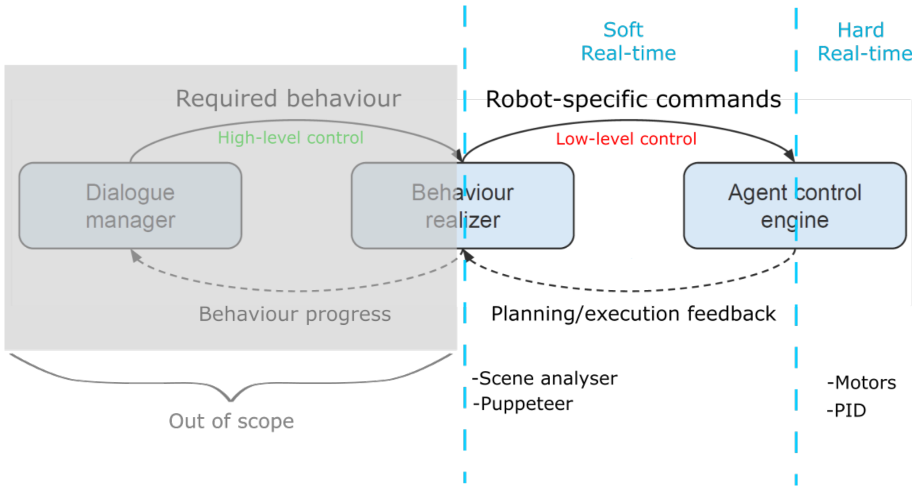


Figure 3.10: Fluent behaviour generator for the Persuasive Social Robot. Source: Davison et al. (2017)

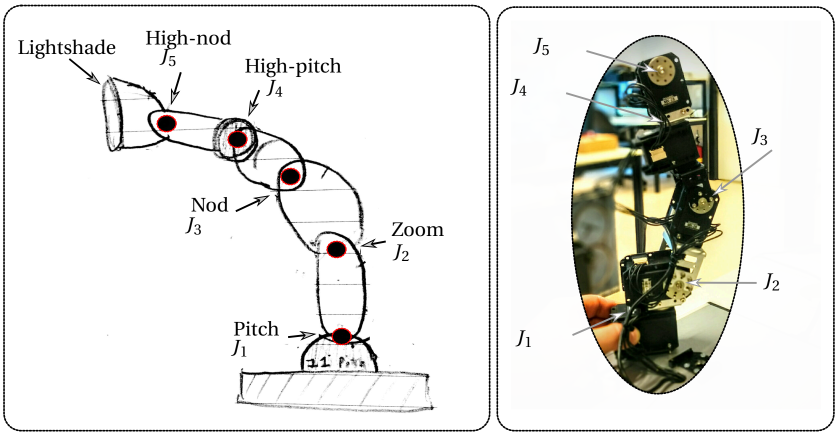
This chapter has reviewed the hardware, software and behavioural requirements of the persuasive social robot. The implementation of the embodied agent comes in the next chapter, along with the HRI tests it was subject.

4 Implementation

The current chapter describes the hardware and software implementation of the persuasive social robot by meeting the previously discussed requirements. First comes the physical assembly of the robot, followed by the modifications and additions made to the RaM HRI Toolkit. Later, each of the HRI experiments to which the robot was subject will be described.

4.1 Robot assembly

Based on a preliminary sketch shown in Fig.4.1-a, the 5 DOF robot arm was assembled in a way that it looks like the desk lamp in Fig.3.4-b. Each of the names given to the joints (see Fig.4.1-a) describe their function in the overall operation of the robot. This feature will become relevant when discussing the software implementation. However, it is important to mention that the *high-pitch* and *high-nod* joints have similar operation ranges as *pitch* and *nod*, respectively. Linked to the *high-nod* joint is the light shade, which works as the end effector of the arm (or head of the social robot).



a) Rough sketch of the DeskLight robot   b) 5 DOF arm assembly

Figure 4.1: Assembly of 5 DOF robot arm. a) Sketch showing each of the names given to the joints. b) Kinematic chain constructed with the DYNAMIXEL motors and brackets.

The light shade is a 3D printed structure illustrated in Fig.4.2. It was of great importance to achieve a design that resembles a real desk light shade. Given this, the inside of the lightshade cone includes a compartment to hold the Arduino micro that controls the LED. The USB connector is placed in a way that the cable connecting the Arduino micro with the main computer enters discretely into the light shade assembly. The LED ring is held in a circular plate which can be easily removed from the cone to have access to the connectors. The final assembly of the light shade is shown in Fig.4.3, which includes the LED ring and the Arduino micro inside.

Just as mentioned in the requirements section, all the electronics were installed inside a case that also works as the base of the desk light. Given the length of the kinematic chain and the movements expected from the robot, a big aluminium control box was chosen to give stability to the whole assembly. The control components and the power supply can be seen in Fig.4.4-a. The front plate of the control box contains the camera assembly; the USB and Ethernet ports; and the power and status LED. The complete control box is shown in Fig.4.4-b.

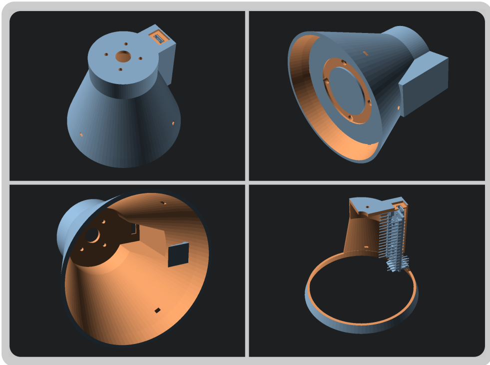


Figure 4.2: Lightshade 3D design.

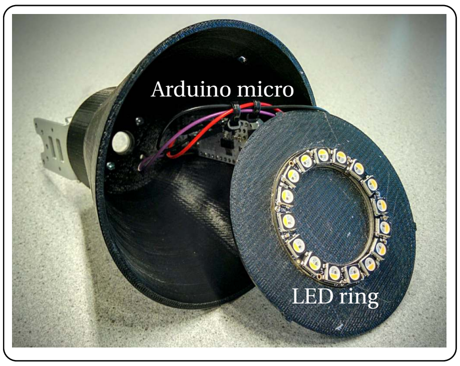
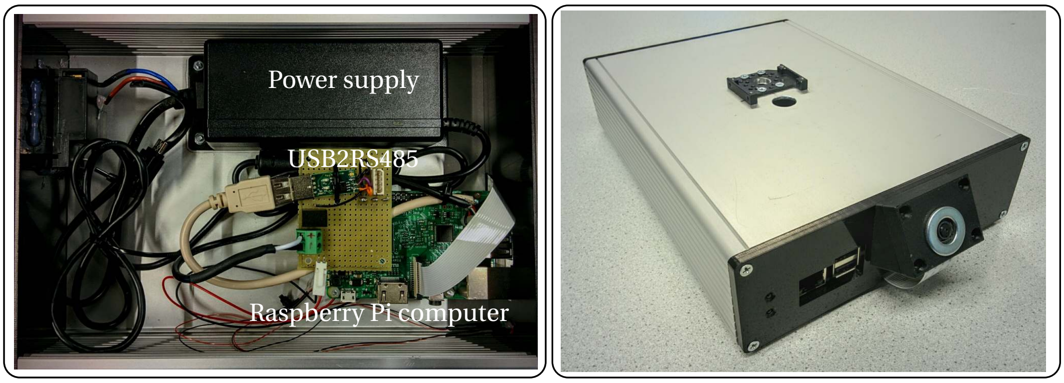


Figure 4.3: Lightshade assembly.



a) Inner content of the control box b) Fully assembled control box

Figure 4.4: a) Power and control components. b) External view of the control box.

Unfortunately, it was not possible to install the Raspberry Pi inside the control box in a way that it was easy to reach the computer's SD card without additional hardware (like a USB hub or extension cord). Nonetheless, the ethernet port in the front panel is enough to access the memory for programming. Although, for a complete backup of the system it is necessary to disassemble parts of the box to take the SD card. The next section explains the software implementation, including the robot's movements and colour displaying.

4.2 Software design

As was pointed in the requirements section, the software framework implemented in the persuasive social robot is the *RaM Human-Robot Interaction Toolkit with Heterogeneous Multilevel Multimodal Mixing* developed over the *ROS* platform. The toolkit controls the angular position of the joints in response to the emulated emotional state or intent sequence of the robot. Similarly, the Arduino micro controls the LED ring according to the state of the robot sent by ROS messages from the main computer. This section describes the upgrading of the HRI Toolkit and its operation, followed by the functions of the LED ring.

4.2.1 HRI Toolkit

The RaM HRI Toolkit provides the fundamentals to convert a robot into a social actor. However, it was developed relying on the presence of a face to communicate with humans. Unlike the *eyePi*, the DeskLight robot has to compensate the lack of facial expressions with body language. Due to this, it was necessary to modify the animation manager inside the framework to make the robot show the required behaviour. The diagram in Fig.4.5 shows a simplified ROS structure of the software, where the *Animator Node* inside the *ram_animator package* can be seen. The Animator component is responsible for commanding the actuators and the facial expressions of the *eyePi*. This node was subject of the main modifications for the persuasive social robot. The rest of the nodes are explained later.

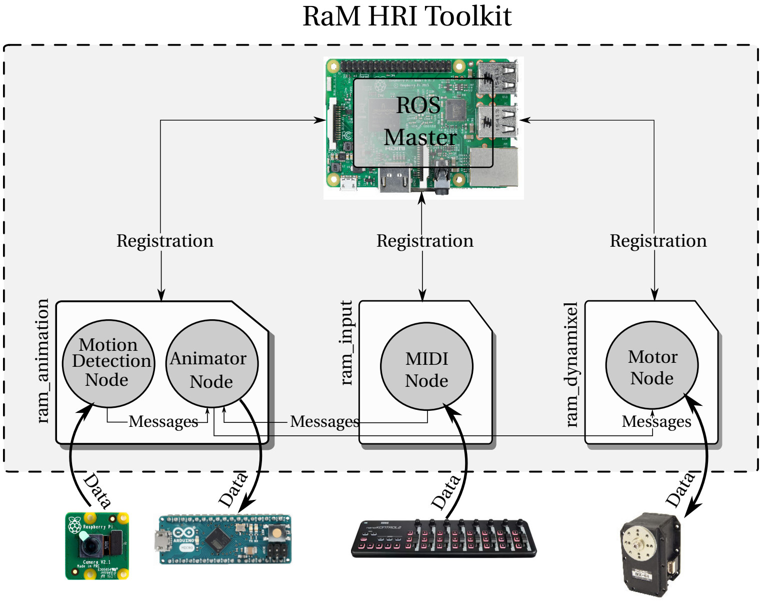


Figure 4.5: Simplified structure of the HRI toolkit on ROS

The Animator Node is directly influenced by the HMMM module and the MIDI controller as represented in Fig.4.6. Once the emotion state of the robot is calculated according to the valence and arousal values, the animator sends messages to the Arduino micro and the motor node. The joint position and the state of the LED ring change accordingly to emulate the desired emotion. The same is for the intent sequences like agreeing or disagreeing, which will be discussed later in this section.

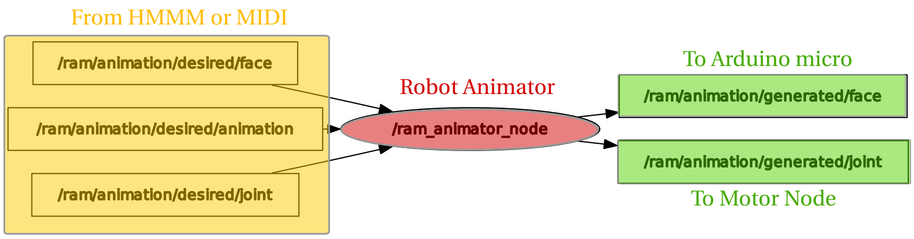


Figure 4.6: ROS graph of the Animator Node

The original *ram_animator package* contains C++ scripts with default sequences for joint positions and facial expressions. For simplicity and easy future adjustments, three more C++ files were added: *expressions.cpp*, *persuasion.cpp* and *sacccadeExpressions.cpp*. The first script contains a single function with the predefined positions of the five joints for each emotion state as in Fig.3.9. Such function is represented in Fig.B.1 as *animateExpressions()*. This programming approach facilitated the adjustment of the joints during the characterization of the emotions. Also, several periodic functions $f(t)$ were added to some of the joints to generate a more dynamic behaviour. The effect of these periodic functions is exemplified by Fig.4.7 and Fig.4.8, where the difference between the expressiveness of the 'Sad' and 'Happy' states is shown. A breathing animation was also incorporated into each of the expressions, although it was a feature already present in the original HRI Toolkit.

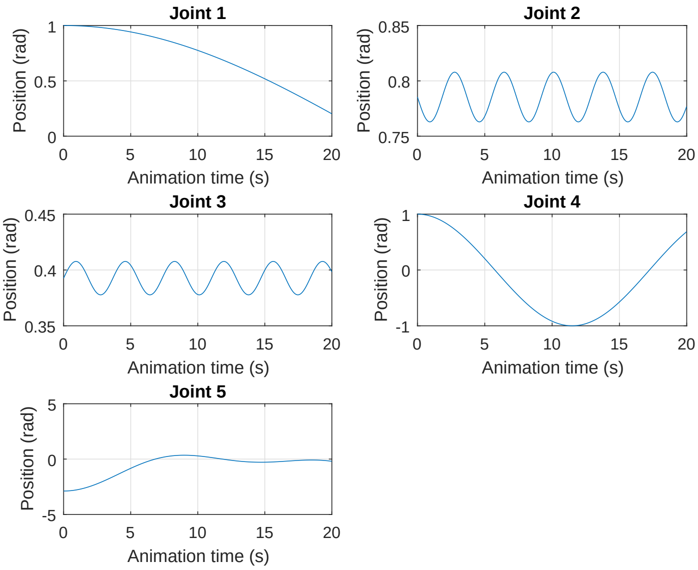


Figure 4.7: Example of Joint animation for the 'Sad' emotion.

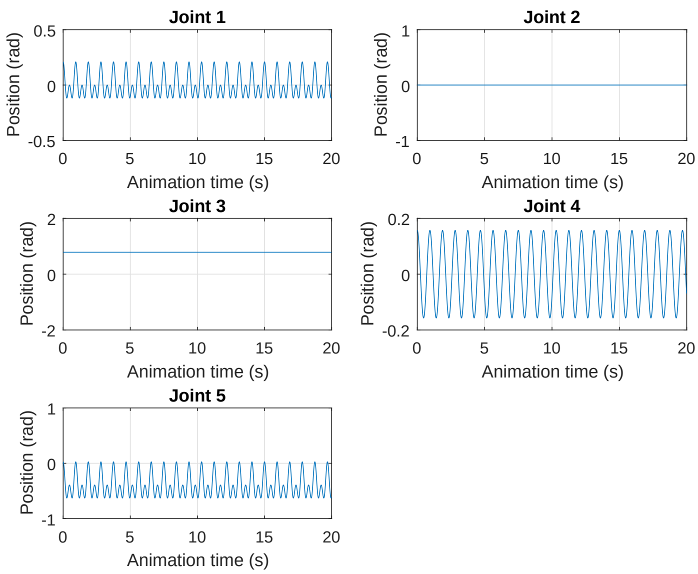


Figure 4.8: Example of Joint animation for the 'Happy' emotion.

Next, come the series of sequences used to express intent. The C++ file *persuasion.cpp* contains a single function with each of the positions of the kinematic chain needed to show other postures such as: standing straight; showing agreement; displaying disagreement; and pointing to a certain position. These sequences are called from the Animator node by pressing designated buttons in the MIDI controller. The flow chart in Fig.B.2 illustrates the function *animatePersuasion* and the hard-coded joint positions for each posture.

The last script, *saccadeExpressions.cpp* merges the gaze (motion detection) of the robot with the emulated emotions. In this way, the social robot can turn to the user while expressing the mentioned emotions. The flowchart diagram in Fig.B.3 illustrates the operation of the function *animateSaccade()*. This code is slightly different from the previous two as joints 1 and 4 use a position variable *xPosSaccade*, and the remaining joints have the variable *yPosSaccade*. The gaze function, operated by the *Motion detection node* through the Raspberry Pi camera, evaluates the position of the most salient point. With this data, the *HMMM node* calculates the X and Y position in the 2D plane to which the robot shall turn to (van de Vijver, 2016), resulting in the variables *xPosSaccade* and *yPosSaccade*. Finally, the *Animator node* via the *saccadeExpressions.cpp* adjusts the angular position of each of the joints. The whole operation is intended to make the robot look at the human user, generating a sense of natural interaction.

As mentioned earlier, the *Animator node* calls the sequences of the emulated emotions, the intent cues and the gaze to dictate the angular position of the joints. Nonetheless, the *pos_to_dynamixel node* (the motor node) is the last stage before proceeding to the motion of the motors. The Fig.4.9 is a representation of how the position message is sent from to each of the Dynamixel motors. The *pos_to_dynamixel node* becomes crucial as any modification in the coding will affect the overall motion of the robot.

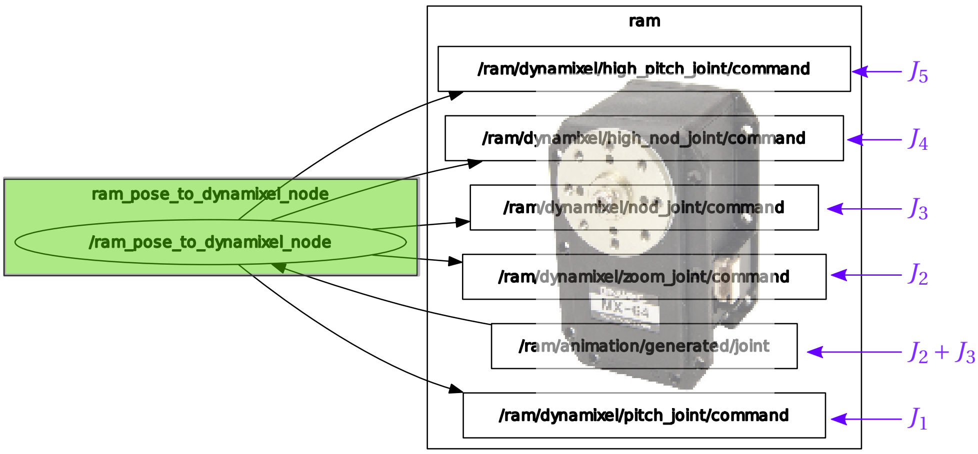


Figure 4.9: ROS graph of the Motor node communicating with each joint.

Now that the sequence scripts and the operation of the *Animator node* have been described, it is necessary to clarify how the joint values are translated into positions of the robot. As an example, Fig.4.10 shows the Zero position and the 'Home' position of the robot. The Zero position is the initial value of the robot when the computer is initialized. Once the Animator node is executed, the robot takes the Home position which is the same as in the Neutral emotion. All the programmed positions in the C++ scripts *expressions.cpp* and *persuasion.cpp* take the Home position as the initial point. The joint values of the Home position with respect to the Zero can be seen in Table 4.1.

No timing improvement has been done to the HRI Toolkit. However, the *rosnode ping –all* instruction shows a response of maximum 4.15ms for the *ram_animator_node* while executing the different animation sequences. The responsiveness of the system is enough to meet the real-time requirement of the interaction. The whole ROS computational map is presented in Fig.C.1 showing the input and output nodes of the Animator component. Among the outputs is the *arduinoSerialConnector node*, which is responsible for controlling the light of the Desk-

Light robot and is described below.

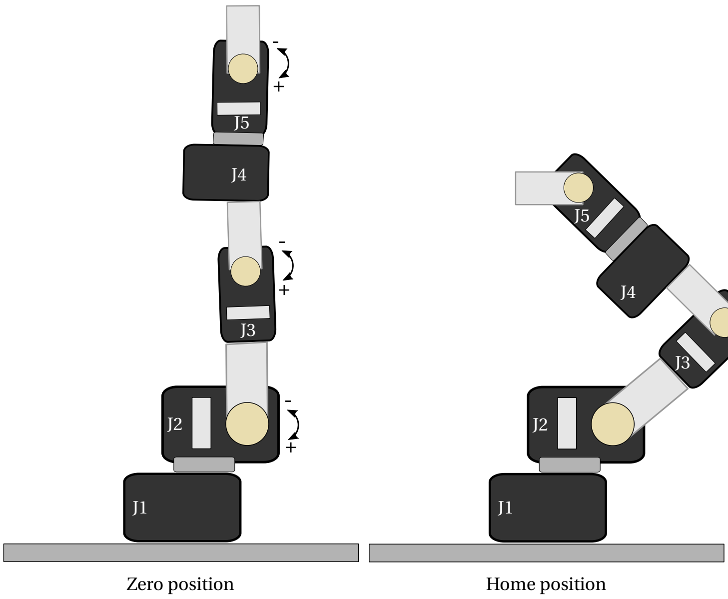


Figure 4.10: Left: Zero position of the joints. Right: Home position of the robot.

Joint	**Angle**
J1	0
J2	$-\pi/4$
J3	$-\pi/2$
J4	0
J5	$-\pi/4$

Table 4.1: Joint angles of the Home position with respect to the Zero.

4.2.2 LED ring control

As represented previously in Fig.3.5 and Fig.4.5, the Arduino micro functions as the interface between the main computer and the LED ring. The Fig.4.11 illustrates how the emotion state of the robot is sent from the *Animator node* to the Arduino through the serial communication node. The LED interface simply reads the incoming ROS message to get the *emotionState* and the *intensity* variables. Due to this architecture, a simple case statement is enough to make the LED show pre-programmed colours and sequences according to the variables in the ROS message.

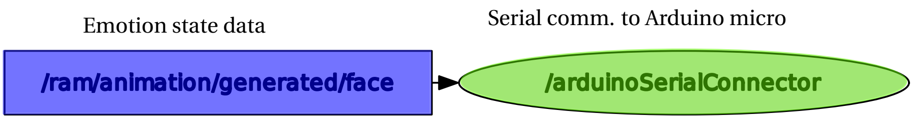


Figure 4.11: Data transmission to the Arduino micro via Serial node

The implemented code for the LED ring control is shown in the following pseudocode:

```
Result: Displaying colors in LED ring
initialization;
while message == true do
    read message;
    case emotionState == EmotionNeutral do
        Set to white;
    end
    case emotionState == EmotionExcited do
        Set to pink;
    end
    case emotionState == EmotionAmazed do
        Set to yellow;
    end
    case emotionState == EmotionSad do
        Set to blue;
    end
    case emotionState == EmotionAngry do
        Set to red;
    end
    case emotionState == EmotionSleepy do
        Turn off;
    end
    case default do
        Set to white;
    end
end
```

Figure 4.12: Algorithm 1: Implemented pseudo-code for the LED ring control

4.2.3 Operation modes

The Fig. 4.13 shows the MIDI controller, which was configured to let the robot operate in 2 different modes:

1. **Autonomous mode:** The robot enables the camera and the motion tracking to adjust the position of its joints. This functionality allows the robot to *gaze* the most salient point. It uses the *saccadeExpressions.cpp* script.

2. **Puppet mode:** The robot's joints and light colours can be freely controlled using the MIDI interface. Nevertheless, the emotion and intent sequences can be executed by pressing a single button, simplifying the task of the puppeteer. It uses the *expressions.cpp* and *persuasion.cpp* scripts.

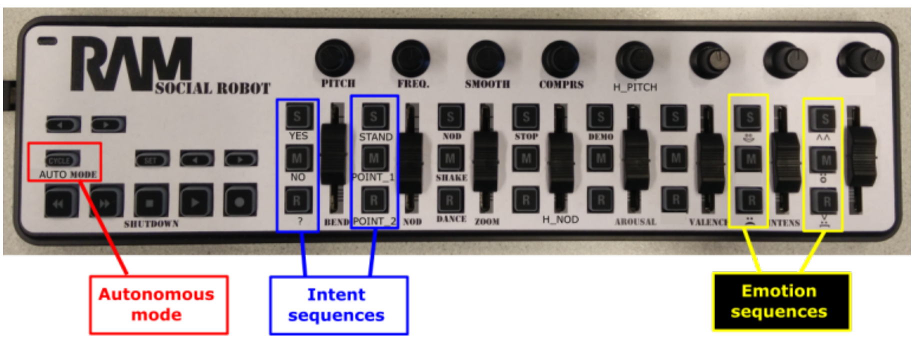


Figure 4.13: MIDI interface. Source: van de Vijver (2016)

As mentioned previously on this chapter, there was no deliberated improvement of the system timing. The ROS update rate of the HRI Toolkis is 100Hz as established in the work of van de Vijver (2016). The *rosnode pin ram_animator_node* instruction outputs a response time of no greater than 5.5ms and average of 3.1ms when changing between both operation modes.

This section has summarised the software development of the persuasive social robot. The original structure of the HRI Toolkit facilitated the required additions and modifications, resulting in an expanded software version that could be implemented to provide persuasiveness to the embodied agent. Next comes the implementation of the Human-Robot Interaction tests.

4.3 HRI experiments

Looking forward to answering the research questions presented in Chapter 1, this section describes each of the HRI tests to which the robot was subject. First, the objective of the experiment will be defined, followed by the details of the procedure and the expected challenges during the interaction. A total of three experiments were implemented, each of them aimed to evaluate the potential of the robot to attracting attention to itself, and showing intent. The results of these tests are found in Chapter 5.

4.3.1 Test 1.- Look at me!

Objective: Qualitatively evaluate the capability of the robot to attract the people's attention.

Justification: As Bettinghaus (1973) states: "Persuasion always involves communication". However, for communication to be effective, the receiver needs to be aware that a message is coming. Given this, it is important for a persuasive agent to attract its target's attention to establish a trustworthy communication channel.

Procedure: High school students (between 16 to 18 years old) were invited to play the video game Super Mario Bros on a desk. This desk contained objects such as pencils, notebooks and a flower pot to create a more 'desk work' kind of environment. The DeskLight robot was placed on one side of the desk. Inside the room, but far away from the desk and the participant, a person was puppeteering the robot as represented in Fig.4.14. The task of the social robot was to take the attention of the participant away from the video game. The task of the participant was getting the higher score possible in the video game to get a prize. At the end of the test, the participants were asked to answer the questionnaire in Fig.E.1. The whole interaction was recorded under prior consent of the participants.

Expected challenge: The robot had to compete against a famous vintage video game released 1983 for the attention of the participant. Despite the DeskLight is a physical thing moving around, it was expected for it to be a challenge to beat the video game.

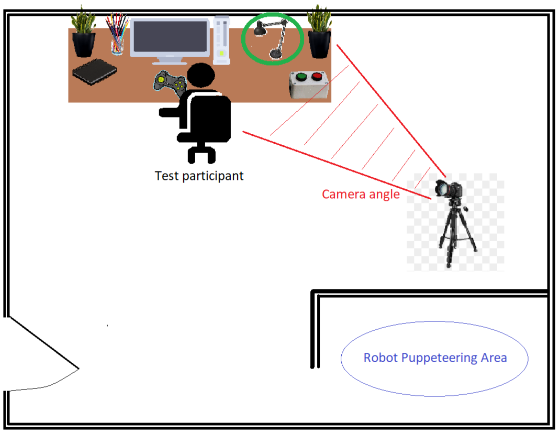


Figure 4.14: Experimental concept of Test 1

4.3.2 Test 2.- Can you press the button, please?

Objective: Qualitatively evaluate the capability of the robot to communicate intent.

Justification: In persuasive communication, the source expects a specific response from the receiver (Bettinghaus, 1973). When the persuasive agent is unable to express intent recognisably, it can not be expected from the receiver to have a proper response. As Bettinghaus (1973) states: "The *intent* of the source [is] to change the behaviour or influence the behaviour of the receiver in a specific manner".

Procedure: The first task of the robot was to catch the attention of any passing-by kid (6 to 9 years old). Once the robot had achieved this, it pointed toward a button box, aside from the robot as in Fig.4.15. By using the LED ring, the DeskLight instructed the kids to press the red or green button according to the colour shown by the light. If the correct button was pressed when the robot asked, the agent proceeded to dance as an expression of gratitude. If the wrong button was pressed, the DeskLigh would shake its body as an expression of disapproval. The whole interaction was recorded under prior consent of the participants' parents. The robot was operated alternatively in two modes:

- Autonomous mode: To attract the children to the setup using the motion detection system (robot gaze).
- Puppet mode: To show the intent cues (e.g. pointing, agreeing, etc.). The puppeteer controlled the robot's behaviour according to the children response.

Expected challenge: It was expected of the kids to interact with the robot naturally. However, it was uncertain if the robot was capable of holding the kids' attention for the whole test.

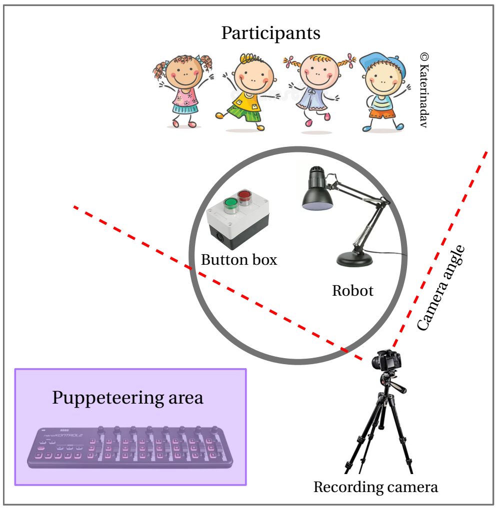


Figure 4.15: Experimental concept of Test 2.
Picture of kids source :
https://www.dreamstime.com/stock-illustration-four-happy-kids-dancing-jumping-image44607137

4.3.3 Test 3.- Do you understand me?

Objective: Qualitatively assess the people's interpretation of the emulated expressions and intent cues of the persuasive social robot.

Justification: The behaviour and emotions of a social robot should be chosen consequently of the individual interacting with it. Likewise, the human actor perceives the robot has personality and looks forward to deciphering what it wants to communicate (Zhao, 2006). Due to this, it is imperative for a persuasive agent to show emotions that can be interpreted adequately.

Procedure: The social robot was introduced to several groups of children (6 to 9 years old) into a one-to-one interaction. The social robot was located over a mat with figures, as shown in Fig.4.16. The first task of the agent was to show its five emulated emotions (Neutral, Happiness, Anger, Sadness and Amaze) to the participants. The second task of the robot was to guide the children to relocate objects (fruits) over the mat using its intent cues such as: standing straight; showing agreement; displaying disagreement; and pointing to a particular direction. The first task of the children was to interpret the robot's message and indicate the emotion shown by the robot using the figures on the mat. The second task of the participants was to relocate objects on the table according to the robot's instructions. An assistant was involved during the test to guide the kids with the task. A puppeteer controlled the robot from an out-of-the-view location. The whole interaction was recorded under prior consent of the participants' parents.

Expected challenge: Given the lack of background or context of the robot's behaviour in the experiment, the children might find difficult to interpret some of the emulated emotions. Nonetheless, their responses were expected to be honest and creative.

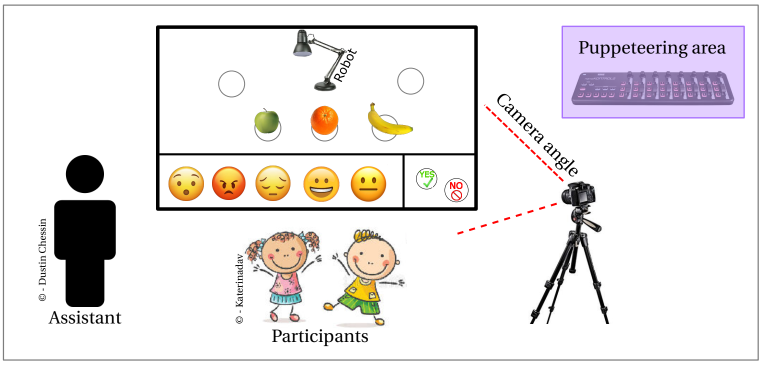


Figure 4.16: Experimental concept of Test 3.
Picture of kids source :
https://www.dreamstime.com/stock-illustration-four-happy-kids-dancing-jumping-image44607137
Picture silhouette source: http://freevector.co/vector-icons/people/person-silhouette.html

As mentioned in Chapter 3, the scope of this project does not include the incorporation of any dialogue manager or behaviour realizer controlling the robot's actions. Due to this limitation, it was decided to operate the robot as a puppet in each of the HRI tests described above. The task of the puppeteer was to evaluate the response of the participants and make the robot show the corresponding emotion or intent sequences to maintain the flow of the interaction. Despite the puppeteer only had to press buttons to execute the sequences, the timing of these actions was critical. If the puppeteer delayed the response of the robot, the interaction would lose its real-time property.

This chapter has summarized the theoretical and technical implementations in the construction of the persuasive social robot. In the chapter that follows, the results and findings of these implementations are presented.

5 Results

The current chapter will be divided into three sections. The first one presents the final iteration of the persuasive social robot under the project's scope. Next follows the resulting nonverbal cues of the robot programmed to communicate intent and express emotions. The last section will disclose the response of the people who interacted with the DeskLight during the tests.

5.1 The robotic social actor

The built DeskLight social robot is shown in Fig.5.1. As mentioned in chapter 4, all the control electronics are hidden either inside the base box or in the light shade. Also, the power cord and the MIDI USB cable are the only external elements connected to the control box. This overall integration of the robot gives a sense of single-unit-embodiment, as could be expected from a real desk lamp.

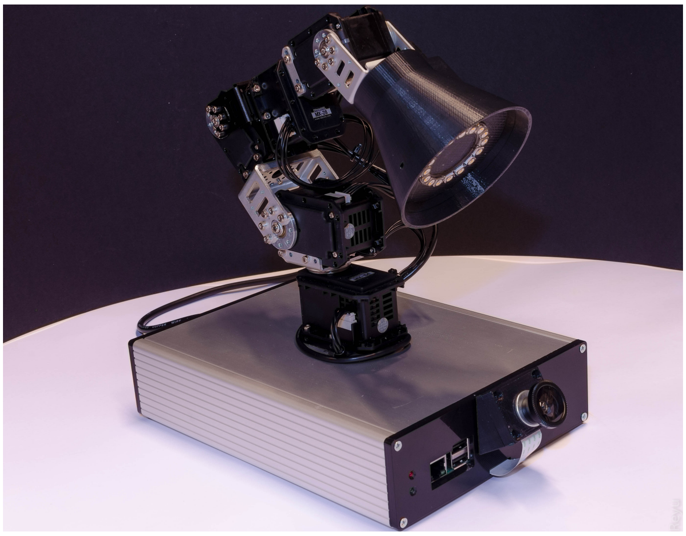


Figure 5.1: The DeskLight social robot

The top view in Fig.5.2 illustrates the size difference between the control box and the kinematic chain. The weight and size of the box give the robot a stable grip to the surface, avoiding any risk of tumbling while moving.

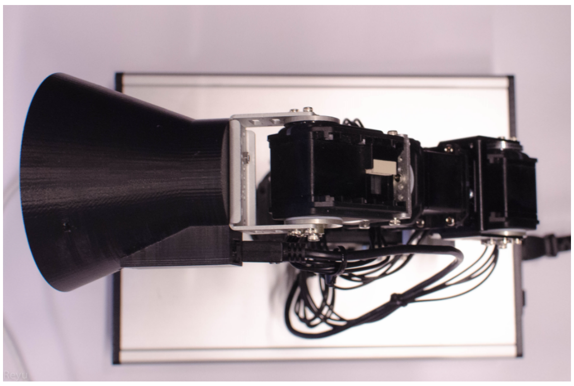


Figure 5.2: Top view of the robot

Better visualization of the kinematic chain is in Fig.5.3, showing the assembly of the 5 Dynamixel motors connected in series and fixed over the control box. In the same away, Fig.5.4 shows each of the joints with their given name.

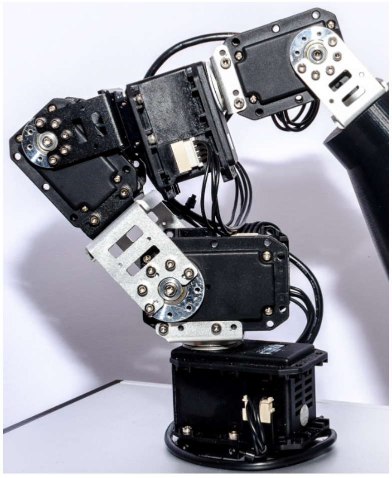


Figure 5.3: Kinematic chain

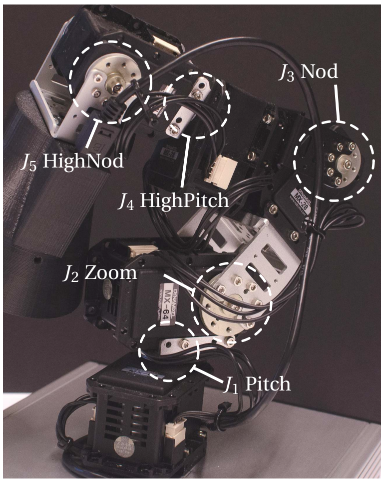


Figure 5.4: The 5 Joints

The DeskLight robot would be just a robotic arm if not for its 3D printed light shade illustrated in Fig.5.5. The fully assembled light shade is fixed at the upper end of the kinematic chain. The assembly includes the LED ring located on the front, crating an illusion of an eye. The design of the cone allows the USB cable connecting the Arduino micro with the Raspberry Pi to be routed discretely on one side of the robot.

Figure 5.5: DeskLight shade with LED ring

The motion tracking camera with its fisheye lens is shown in Fig.5.6. The USB port for the MIDI controller and the Ethernet connector are located on this front plate, which becomes handy when operating the robot or accessing the Raspberry Pi computer for any joint angle adjustment.

Figure 5.6: Front plate of the control box

The whole system complies with the intended portability and the minimalistic design. Due to its construction and materials, the DeskLight robot is robust and durable. Nevertheless, the light shade assembly might be the most fragile component because of the 3D printed plastic. In conclusion, the social robot resembles a real desk lamp as represented in Fig.5.7.

Figure 5.7: DeskLight robot as a lamp for desk work.

5.2 Robot's nonverbal cues

This section presents the resulting nonverbal communication functions of the robot. Particular attention is given to the expressiveness of the motion and the colour shown by the LED ring. For each of the emotional states and intent cues, there are two pictures, one showing a static posture of the robot and the second displaying its movement in a long exposure photo.

5.2.1 Neutral state

Neutral is the standard emotion state of the social robot. The light from the lamp is white as an expression of neutrality. Also, it is the expected colour of any desk lamp. The long exposure picture in Fig.5.9 illustrates the breathing motion of the robot. As a neutral emotion, there is no additional animation. The joint positions of this sequence are shown in Fig.D.1.

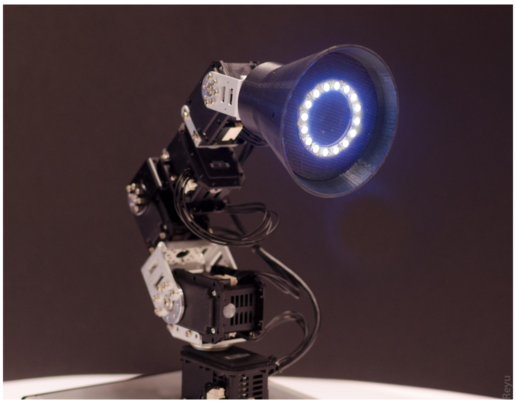


Figure 5.8: Neutral expression

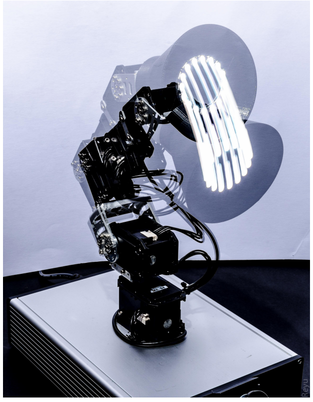


Figure 5.9: Neutral on the move

The resulting posture shown in Fig.5.8 is the one expected on any desk lamp. The head of the DeskLight is located in a middle height position, emulating a natural and relaxed attitude.

5.2.2 Happy state

This is the state of the social robot intended to express happiness. The pink light of the lamp is supposed of displaying sympathy and joy. The long exposure picture in Fig.5.11 shows the dynamism in the movements of joints J_1, J_4 and J_5. The joint positions of this sequence are shown in Fig.D.2.

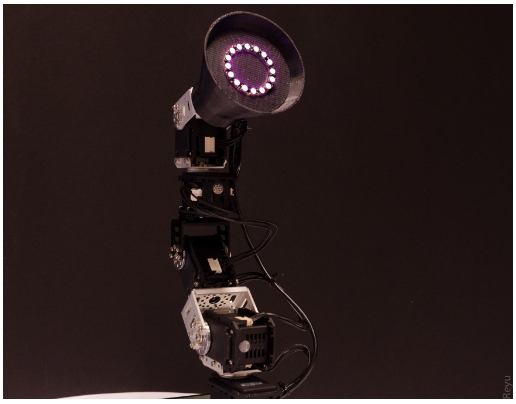


Figure 5.10: Happy expression

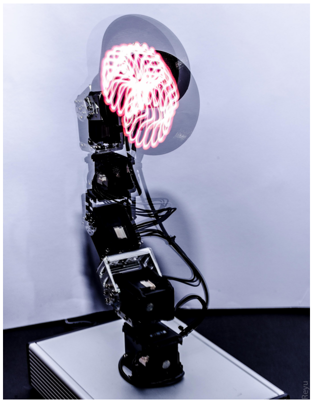


Figure 5.11: Happy on the move

The joints of the robot in Fig.5.10 locates the head in an elevated position. This posture and the animation of the joints allow the embodied agent to show positive arousal and positive valence.

5.2.3 Amazed state

This is the state of the DeskLight intended to express amaze or surprise. The light coming from the lamp is a combination of green and yellow trying to exhibit either vigour or danger. The long exposure photo in Fig.5.13 illustrates the exaggerated breathing of the robot as it would be shown by a person who has been scared or surprised. The joint positions of this sequence are shown in Fig.D.4.

The head position of the robot as in Fig.5.12 is located in an elevated position to show positive valence. However, the posture is leaned back as it would be the natural reaction of an amazed person.

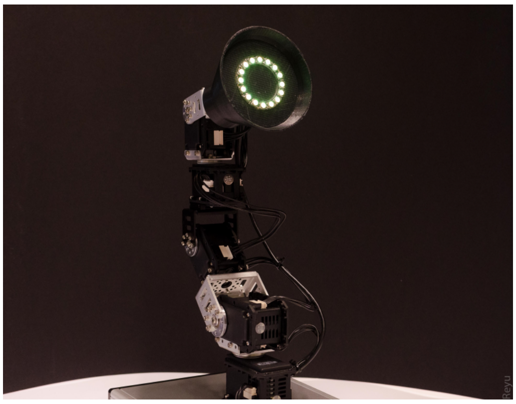


Figure 5.12: Amazed expression

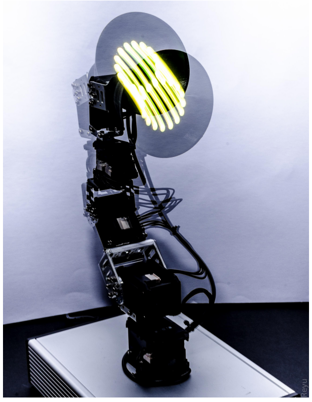


Figure 5.13: Amazed on the move

5.2.4 Angry state

This is the state of the robot programmed to manifest anger. The light displayed by the lamp is red coloured as a sign of danger and anger. The long exposure photo in Fig.5.15 illustrates the vigorous shake of the robot's head as it would be shown by the body of a person who is enraged. The joint positions of this sequence are shown in Fig.D.3.

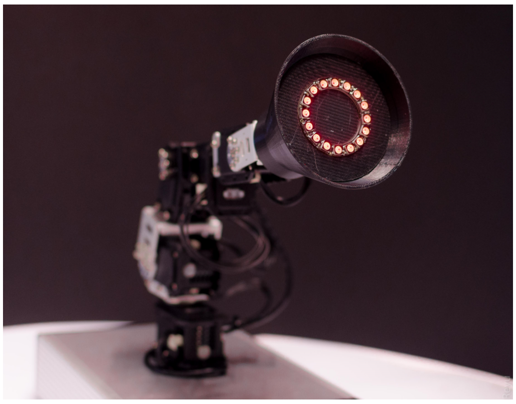


Figure 5.14: Angry expression

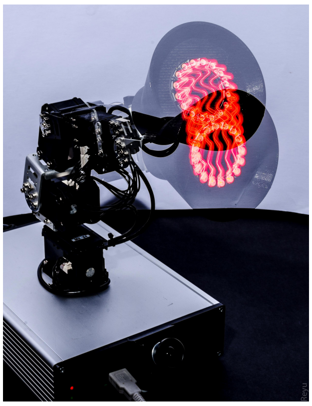


Figure 5.15: Angry on the move

The whole position of the robot is lowered to show negative valence, but with increased proximity to the user (see Fig.5.14) as an attempt to invade their intimate space.

5.2.5 Sad state

This emotion state is intended for displaying sadness through a blue coloured light. The long exposure picture in Fig.5.17 shows the robot's head leaned down, which is an attitude expected of any sad person. The joint positions of this sequence are shown in Fig.D.5.

The lowered head and the slow movements of the robot give the impression of sobbing or sighing.

Figure 5.16: Sad expression

Figure 5.17: Sad on the move

5.2.6 Sleepy state

It was decided to combine the sleepy state of the robot with its shutdown procedure. This choice resulted in taking out the sleepy expression from the emotion sequences so that it can be activated only when the shutdown button is pressed. The steps of the sleepy mode are described in the following order:

Once the *Shutdown* button in the MIDI is pressed:

1. Stop any running sequence.
2. Turn the LED colour to blue.
3. Move in joint space to the safe, *sleepy* position.
4. Turn off the LED light.
5. Shutdown ROS.

It was intended to make the robot express some sadness when the shutdown button is pressed, for this reason, the LED light is turned to blue. The Fig.5.18 shows the final joint position of the DeskLight once the shutdown sequence has finished.

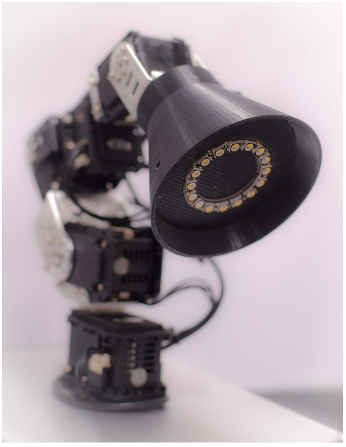


Figure 5.18: DeskLight robot in shutdown/sleeping position.

5.2.7 Standing straight

This posture places the kinematic chain in a vertical position with joint J_5 rotated +90° with respect to the zero (see Fig.4.10). With this joint angles, the robot looks like standing straight while looking forward, as if asking for attention with a hand up. Fig.5.19 illustrates this position.

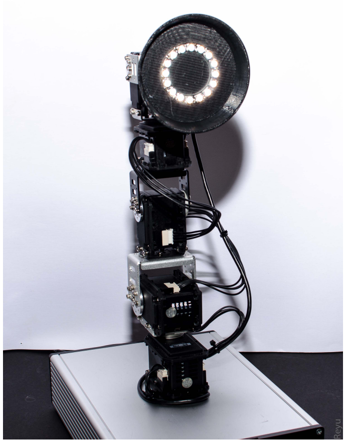


Figure 5.19: DeskLight standing straight.

The behaviour shown in this sequence works as a method to attract attention before engaging in any HRI. With this posture, it could be possible to let the human user know that a message or request is coming from the robot.

5.2.8 Agreeing & disagreeing

Being able to communicate agreement and disagreement is crucial for any interaction, specially during a cooperative situation. As humans, just a simple head movement is enough to say 'yes' and 'no'. In the same way, the social robot moves the light shade to simulate this expression. The Fig.5.20 illustrates the movement of joints J_3 and J_5, making the robot nod as if it is agreeing. On the other hand, Fig.5.21 shows the rotation of joints J_1 and J_4, causing the robot's head to shake as if saying 'no'.

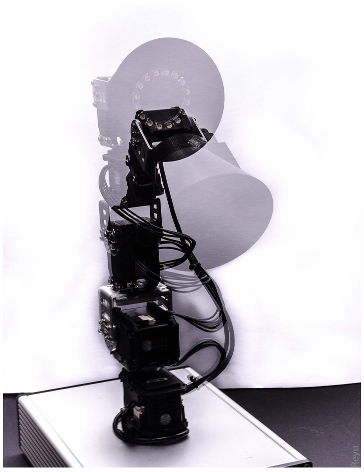


Figure 5.20: DeskLight showing being agree.

Figure 5.21: DeskLight showing being disagree.

5.2.9 Pointing

It is a fact that the robot lacks limbs. However, this design does not limit its capability to point toward a certain direction. The Fig.5.22 demonstrates that the whole kinematic chain can be used to give a signal, changing the attention from the robot to another object. This sequence can be applied to task-related interactions. In persuasive situations, this feature becomes critical when requesting a person to perform a task or to pay attention to something else.

Figure 5.22: DeskLight pointing toward a button box.

5.2.10 Emotional gaze

The *RAM HRI Toolkit with Heterogeneous Multilevel Multimodal Mixing* has a feature which uses the Raspberry Pi camera that makes the embodied agent gaze toward the most salient point, as was mentioned in Chapter 4. This operation mode increases the interactivity between the robot and the user. The emulated emotions merged with the gaze resulted in the behaviors shown in Fig.5.23.

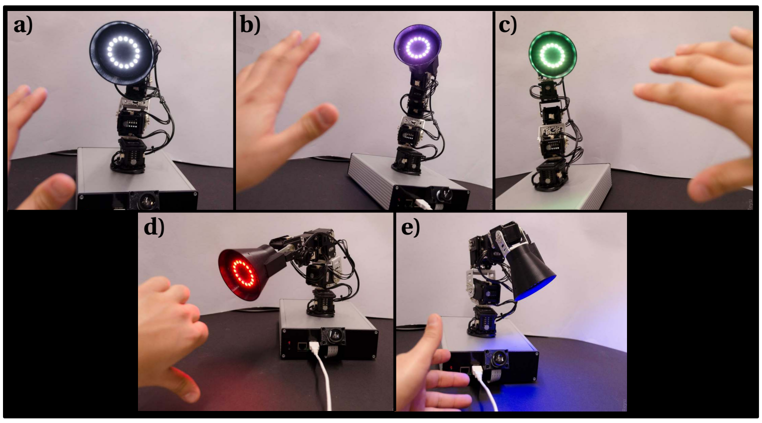


Figure 5.23: Different gaze behaviors: a) Neutral, b) Happy, c) Amazed, d) Angry, e) Sad.

The characteristics of each of the emulated emotions are held during gazing mode. Referred to Fig.5.23, the *a)* neutral mode just follows the most salient point with an apparent peaceful mood. In the *b)* happy state the robot's head is elevated, while in *c)* amazed mode the body is leaned back. When the emulated emotion is *d)* anger, the robot is leaned forward-down, emulating a challenging gaze. All the mentioned emotion states use the motion tracking to make the robot look toward the user. On the other hand, the *e)* sad mode lower the head of the robot to the floor, but the whole body turns away from the user as if trying to avoid any contact.

These have been the behavioural results of the robot, where it can be said that all the sequences seem expressive and natural. The Dynamixel motors have an embedded PID controller which was reconfigured to improve the smoothness of the movements. By strategically decreasing the P-gain, it was possible to give the robot a more natural motion. This configuration compromises the speed and precision of the motion, yet these features are not critical given the purpose of the DeskLight. It has to be mentioned that the behaviour of the robot changes immediately when executing the animation sequences by pressing the different buttons in the MIDI controller.

5.3 HRI results

As mentioned in Chapter 4, there were three HRI tests designed to evaluate the communication skills of the social robot needed to later engage in persuasive interactions. The first experiment evaluated whether or not the DeskLigh is capable of attracting the attention of a person. The second test assessed the potential of the robot to communicate intent. The third and last test evaluated the interpretation of the emulated emotions and intent cues of the robot. This section presents the qualitative results obtained from the Human-Robot interactions.

5.3.1 Test 1

Returning briefly to what was explained in the Implementation chapter, the participants were encouraged to obtain the highest score in the video game *Super Mario Bros* by playing during 5 minutes. To avoid any possible biasing; it was never told to the players of the presence and purpose of the robot. As shown in the setup picture in Fig.5.24, the DeskLight was located close to the participant and the TV screen where the game was displayed. Given the format of the experiment and the people available for testing, only three recorded exercises were done. The log of events of this test can be found in Appendix E.

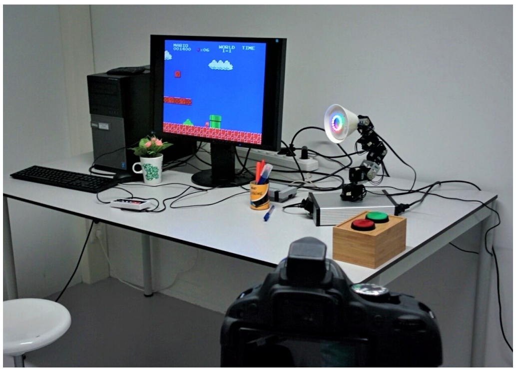


Figure 5.24: Setup for Test 1

The collected footage indicates that the robot was unable to take the attention of the players from the video game while playing. The Fig.5.25 and Fig.5.26 show the number of times that participants #2 and #3 looked at the robot and the duration of the interaction. It has to be mentioned that the footage of participant #1 was discarded due to the bad quality of the recording. Only during the game's transition cutscenes or while the 'game over' screen was shown, the participants turned their eyes from the TV to look at the robot. However, once the video game resumed, the participants' attention changed immediately back to the TV screen. A box with buttons was placed on the desk a bit far from the participants while the robot was pointing toward it. None of the participants got the hint that the robot was trying to persuade them to stop playing the game to press one of the buttons on the box.

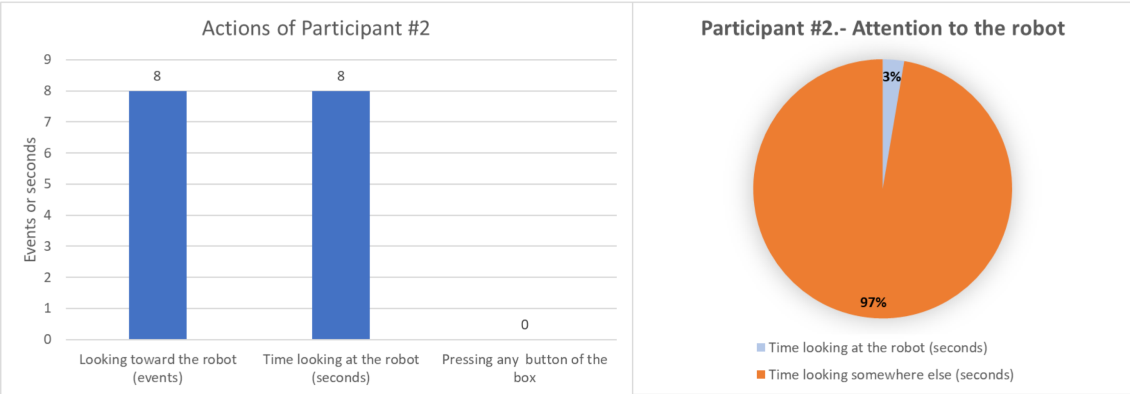


Figure 5.25: Results of participant #2

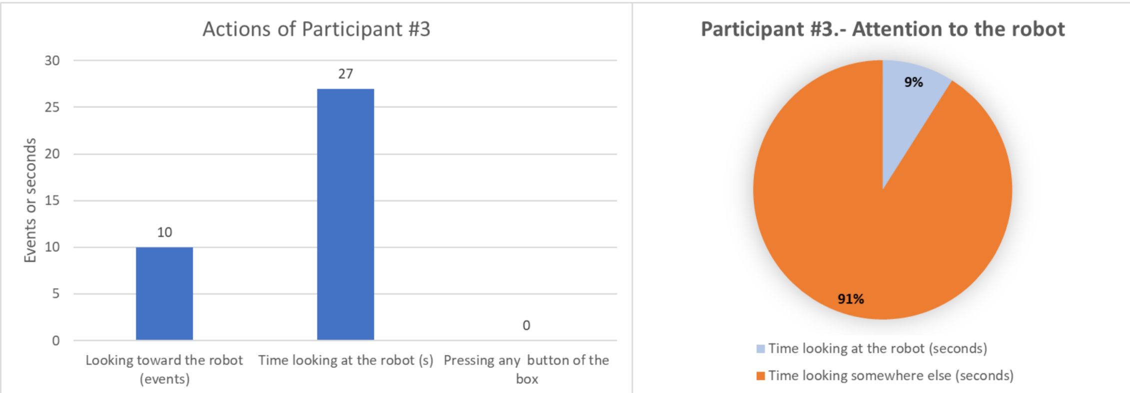


Figure 5.26: Results of participant #3

Based on the responses obtained from the questionnaire in Fig.E.1, the participants indicated that the first element which caught their attention when arriving at the desk for the first time was the video game. Despite the robot is a physical thing moving around, *Super Mario Bros* was more important for the participants as there was a task of getting the highest score to obtain a prize (see Fig.5.27). Nonetheless, all the participants indicated that the robot attracted their attention while playing. Regarding the look and behaviour of the robot, none of the participants felt discomfort with having the robot nearby.

Figure 5.27: Interaction in Test 1

From these results it can be concluded that the DeskLight is capable of attracting the people's attention. Nevertheless, it was also demonstrated that whoever interacts with the robot should be aware beforehand of its presence and purpose. In other words, when engaging in task-related HRI, the human counterpart must know that interacting with the robot is necessary to complete the objectives. If this condition is not satisfied, the attention obtained by the social robot will be just mere curiosity. During the test, the participants' attention was taken from the video game to the robot for a brief time. This interaction was not enough to persuade the participants to do anything more than playing.

5.3.2 Test 2

Given the results of Test 1, the strategy for Test 2 was modified to let the robot have all the attention by removing any other object that could distract the participant. As mentioned in Chapter 4, the participants for the second experiment were children between 6 to 9 years old who went to the University of Twente for a school trip. During the session, the children had the chance to interact with diverse academic projects, the DeskLight social robot being one of them. The test, whose setup is shown in Fig.5.28, was carried out during this visit. The log of events of this test can be found in Appendix F.

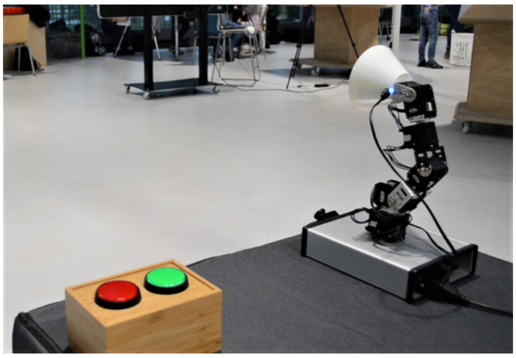


Figure 5.28: Setup for Test 2

The goal of the robot was to persuade the children to press the correct button either red or green. For this, the DeskLight used nonverbal cues such as agreeing, disagreeing, pointing and standing straight to communicate intent to the children. The collected footage shows a total of 13 different interactions between the children and the robot (see Fig.5.29). As expected, under this circumstances the robot was able to catch the needed attention to proceed to deliver a persuasive message. Although during the whole test the robot pointed toward the button box 68 times, the response of the children was not immediate as the message is not coming from an anthropomorphic agent.

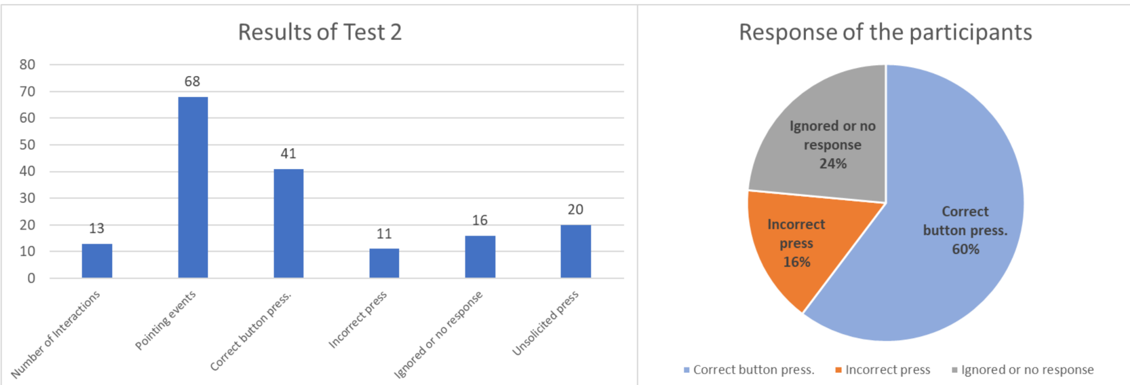


Figure 5.29: Results of Test 2

On several occasions, the message was not clear enough, and the participants ignored the robot's request (16 events, 24% of the responses). Other children understood the cues partially and pressed the wrong button (11 events, 16% of the responses). Some of the children decided to press the buttons without the request of the robot (20 events). However, the children pressed the correct buttons when indicated the 60% of the times. The plot in Fig.5.30 shows no correlation between the duration of the interaction and the number of correct buttons pressed. An explanation of this last result could be the several times some of the children pressed the wrong button derivatively to test the robot's response. Also, the delayed timing of the puppeteer controlling the robot might have influenced the children to ignore the request or press the wrong button.

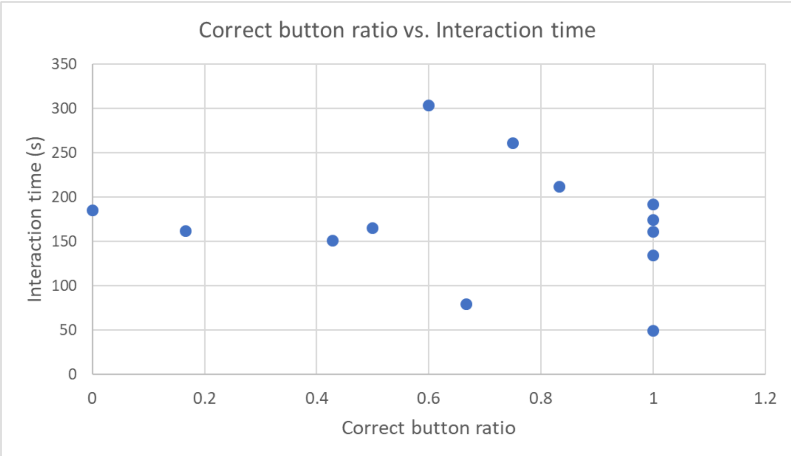


Figure 5.30: Correct button vs. interaction time

The results of Test 2 showed that the nonverbal cues programmed to communicate intent were effective. In most of the occasions, the children understood what the robot was communicating and seemed to be willing to cooperate with it as portrayed in Fig.5.31. Also, the usage of the agreeing and disagreeing sequences helped to guide the children through the interaction. This outcome was only possible once the DeskLight had caught the attention of the children.

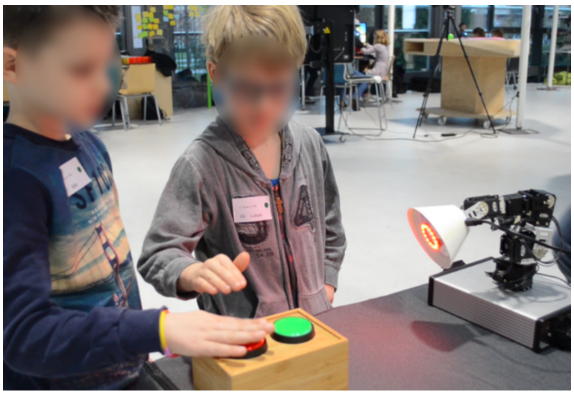


Figure 5.31: Interaction in Test 2

5.3.3 Test 3

The approach for Test 3 was much different than on the previous two. In this case, the robot had all the attention as the task required interacting with it. A total of 64 children participated in the test. After all the members of the group were introduced to the activity, the kids were asked to come forward one-by-one to interact with the robot. In each group, some kids were asked to identify the emulated emotion of the robot and indicate it in the mat using the figures as in Fig.5.32. The rest of the participants in the group were asked to follow the instructions of the robot to relocate the fruits over the mat.

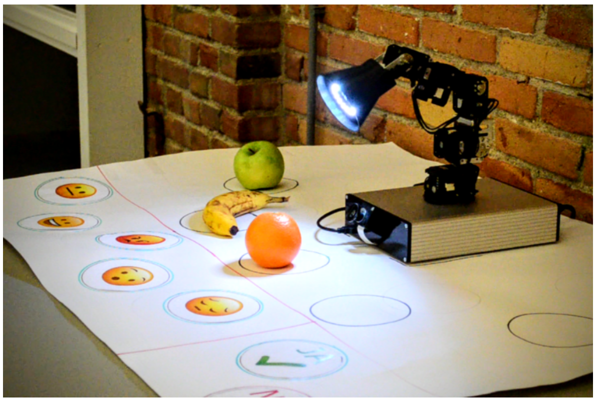


Figure 5.32: Setup for Test 3

The emotion identification task consisted in 7 rounds with five children participating on each one (35 kids in total). On a round, the five emulated emotions of the robot were shown to the five children, one child per emotion. In other words, each emotion had the chance to be identified seven times. The response of the participants according to the emulated emotion showed by the robot can be seen in Table 5.1. The *Sad* and *Angry* states were identified in all the rounds (7 of 7). On the other hand, the children had difficulties identifying the rest of the emotions. For instance, the *Happy* state was confused with the *Angry* expression, while the *Amazed* emotion of the robot was confused with the *Happy* state. Interestingly, the *Neutral* was the most difficult emotion to identify.

		Identified Emotion by the children					**Other responses**	
		Happy	***Sad***	***Angry***	***Amazed***	***Neutral***	***Yes***	***No***
Emulated Emotion	***Happy***	**14%**	0%	86%	0%	0%	0%	0%
	Sad	0%	**100%**	0%	0%	0%	0%	0%
	Angry	0%	0%	**100%**	0%	0%	0%	0%
	Amazed	43%	14%	0%	**29%**	0%	14%	0%
	Neutral	29%	29%	0%	0%	**14%**	29%	0%

Table 5.1: Results of Test 3: Emulated emotions

A total of 29 children participated in the second task, also divided into seven groups. Each of the participants was asked to interact with the robot and interpret its actions. The DeskLight was controlled to point to a particular direction and use the agreeing and disagreeing cues to convince each child to relocate one of the fruits. Surprisingly, all of the participants were able to understand what the robot was trying to tell and successfully relocated the fruit as indicated.

The collected footage shows that the emulated emotions of the DeskLight can be identified by people. As expected, not all the emotions can be recognised without any context. Some of the emotions were confused with the *yes/agreeing* cue due to the breathing animation of the robot. As each child observed one emotion only, the difficulty of the task was high as they did not have the chance to see the other expressions for comparison. Again, this test has demonstrated that the embodied agent can communicate intent to give instructions using non-verbal cues as shown in Fig.5.33. It has to mentioned that some context was given to the children by telling that the robot wanted them to do something. In this way, the participants were aware of the request coming from the robot.

Figure 5.33: Interaction in Test 3

To conclude this chapter, it should be mentioned that Test 1 and 2 used the first iteration of the DeskLight. Nonetheless, this does not affect the outcome. The final and most capable version of the robot was used in Test 3. Interestingly, some traits of the personality of the people interacting with the embodied agent were observed. For example, during Test 1 a participant felt that the robot was disappointed for his/her lousy performance during the game. Similarly, in Test 2 some children played and danced with the robot after pressing the indicated button. In summary, these results have shown that the developed social robot is capable of attracting the people's attention and communicating emotions and intent. However, further work needs to be done to improve the interpretation of some emulated emotions. The next and final chapter presents the conclusions and the following steps proposed for this project.

6 Conclusion & Further Work

6.1 Conclusions

The present research project was designed to explore the persuasive power of social robots. The analysed bibliography pointed out that persuasiveness is a necessary characteristic for robots developed to assist humans. It was also found that most of the HRI research rely on the anthropomorphism of the embodied agent to efficiently deliver a message to the human receiver. The main reason is that the usage of the face and limbs of the social robot guarantee partially the ease of interpretation of the communication due to their resemblance to a human. The analysis undertaken here has shown that there is an unexploited potential regarding the persuasiveness of non-anthropomorphic robots.

The anthropomorphism of the robot highly increases its requirements and elevates the people's expectation of the robot's appearance and behaviour. Due to this problem, it was proposed that a 5-DOF robot arm could be an optimal solution to develop a persuasive social actor. The robot was given the shape of a classic desk lamp, with a 3D printed light shade and a LED ring as the source of light. Given the lack of face and limbs of the robot, it had to rely on nonverbal language such as postures, gaze, proximity and expressions to communicate. It was chosen to avoid the use of verbal communication to exploit all the potential of the robot's body language. The goal of this project was the construction of the robot and provide it with behaviour such that people could interpret its intent cues and expressions.

The resultant robot can show five emulated emotions and four intent cues with total expressiveness. This behaviour was achieved by focusing on the motion of each of the actuators in joint space. As this project proposes the physical embodiment to provide of persuasive skills to the agent, it was necessary to generate real interaction opportunities. The HRI tests demonstrated that the DeskLight is capable of attracting the people's attention and communicating intent. However, it was found that the effectiveness of the communication not only depends on the behaviour of the robot but also in the conditions of the interaction.

Test 1 showed that the social robot would not get the required attention if the user is unfamiliar with the agent and its purpose. The Test 2 suggested that the nonverbal communication skills of the robot are enough to express intent. Finally, Test 3 revelled the potential of the robot to give instructions by pointing, agreeing and disagreeing. However, not all the emulated emotions can be identified without context or a background story. These results indicate that the most critical limitation lies in the non-anthropomorphism of the robot itself, as it increases the difficulty of the interpretation of the nonverbal cues. It was also found that delayed responsiveness of the puppeteer influences the identification of the robot's actions negatively.

Within the scope of this thesis project, the following gives answer to the research questions stated in Chapter 1 :

How can a non-humanoid robot become a persuasive social agent?

The analysis done in Chapter 2 suggests that persuasiveness is a communication skill which has particular requirements. First of all, the social robot needs to be attractive in its appearance and behaviour. The agent not only requires a positive affinity from the user, but it also needs to catch the attention to deliver the persuasive message efficiently. Once this connection is achieved, the robot needs reliable nonverbal cues such as posture, gaze, proximity and expressions to communicate intent.

Is the design and behaviour of the robot capable of attracting people's attention?

Yes. The results exposed in Chapter 5 have shown that the robot can attract attention just because is a physical thing moving around, which is something that can not just be ignored. However, the user will not give the robot enough attention if the task at hand does not explicitly involves the cooperation with the agent.

How can a non-humanoid robot express emulated emotions using nonverbal communication only?

Chapter 3 has addressed the requirements for a persuasive social robot to communicate emulated emotions through body language and colours. Despite the DeskLight is non-anthropomorphic, the light shade resembles a head which posture can be set to simulate some human inspired expressions. Moreover, it is proposed to use different light colours to reinforce the interpretation of the robot's emotional state. The Test 3 showed that some emulated emotions could be identified by using these techniques. Nevertheless, the behaviour of the non-anthropomorphic robot shall be accompanied by a situational context to help the user interpret the expressed emotions.

To what extent can the robot communicate intent through nonverbal communication?

In the same way that emotions can be expressed through body language, intent cues can be communicated using the robot's kinematic chain. The human body joint space movements such as nodding to show agreement or rotating the head to disagree can be implemented in a robot.

This work contributes to the existing knowledge of HRI by providing an overview of the requirements for a non-anthropomorphic robot to become a persuasive social actor. After expanding the *RAM HRI Toolkit with Heterogeneous Multilevel Multimodal Mixing* it was possible to develop a non-humanoid robot capable of communicating intent and emulated emotions. These two characteristics, along with a positive affinity toward the robot, are requisites to engage in effective Persuasive Human-Robot Interactions.

6.2 Further Work & Recommendations

Persuasiveness in social robots is a topic that has too much to offer and grow. The RaM HRI Toolkit has demonstrated to be a reliable platform to develop social robots. However, further work needs to be done to achieve the behaviour needed to perform efficient Persuasive HRI. A notorious limitation of this project is the low autonomy of the robot due to the lack of a user model to which the robot's behaviour could be shaped around. Given this, it is suggested to guarantee the predictability and reliability by developing a competent user model using persona-based scenarios. This would also help the user to identify the emulated emotions.

A greater focus on the vision system of the DeskLight is needed as it is insufficient to identify the response of the user. Without the means to perceive what the user is communicating, it would be impossible for the robot to shape the course of the interaction. Developing a face recognition system capable of identifying the user's body language would provide the social robot with powerful, persuasive capabilities. Also, it is recommended to incorporate capacitive sensors and microphones to make the social robot aware of its environment and react to it.

Persuasiveness also implies questioning choices for re-evaluation. However, the current state of the DeskLight robot does not have a reliable body posture for questioning the user as this communication feature is more complicated due to its context dependency. It is recommended to apply a scenario-based behaviour realizer with the support of a dialogue manager to make the robot's intentions clearer when questioning. Also, the addition of nonverbal sounds might give support to the movements of the robot as in the *Luxo Jr.* film.

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This master wouldn't be possible without the support of the *Instituto de Innovacion y Transferencia Tecnologica de Nuevo Leon* (http://i2t2.org.mx/) and *Consejo Nacional de Ciencia y Tecnologia* (https://www.conacyt.gob.mx/). Thanks for keep providing these scholarships to the ones who dare to do more.

Thank you for giving me the opportunity.

"But if you make yourself more than just a man,
if you devote yourself to an ideal, [...],
then you become something else entirely." - Ra's Al Ghul
Batman Begins (2005)

Reynaldo Cobos Mendez
Enschede, March 2018.

A Appendix 1 - Component list

Class	Description	Part No.	Manuf.	Req.	ECPP(euro)	ETC
Actuator	Dynamixel MX-64R	902-0065-000	Robotis	2	260.23	520.46
	Dynamixel MX-28R	902-0064-000	Robotis	3	192.16	576.48
Brackets	FR05-B101K Set	903-0153-100	Robotis	1	27.14	27.14
	FR05-S101K Set	903-0152-100	Robotis	1	12.67	12.67
	FR05-H101K Set	903-0151-100	Robotis	1	25.44	25.44
	FR07-H101K Set	903-0159-100	Robotis	2	23.73	47.46
	FR07-S101K Set	903-0160-100	Robotis	1	10.12	10.12
Cables	Robot Cable-X4P 180mm	903-0244-000	Robotis	1	14.37	14.37
	Robot Cable-X4P 100mm	903-0243-000	Robotis	1	11.82	11.82
	Flat Micro-USB cable	VLMP60410B1.00	Valueline	1	3.95	3.95
Ctrl	Rapsberry Pi	RASPBERRY PI 3	Raspberry Pi	1	34.39	34.39
	Raspberry Pi Camera Module	913-2664	Raspberry Pi	1	25.71	25.71
	Arduino Micro	ARD-A000053	Arduino	1	21.95	21.95
	FTDI USB-RS485 converter	USB-RS485-PCBA	FTDI Chip	1	32.11	32.11
	NeoPixel 16 LED ring	ADA-2854	Adafruit	1	13.95	13.95
	DC-DC converter 5V	SR10S05	XP Power	1	7.63	7.63
Power	Power,Entry Connector	JR-101-1-FRSG-02	multicomp	1	7.17	7.17
	12V,power supply	125-4247	RS Pro	1	20.36	20.36
	3mm Red,LED	L05R3000F1	LED Technology	2	0.111	0.222
	3mm,Green LED	L02R3000F1	LED Technology	2	0.148	0.296
Misc.	PCB prototypinbg board	AGP10	CIF	1	12.24	12.24
	Flash Memory Card	TS8GUSDHC10	Trascend	1	29.09	29.09
	Metalic enclosure	1455T2201	HAMMOND	1	37.26	37.26

Table A.1: Bill of Materials

B Appendix 2 - C++ Flow charts

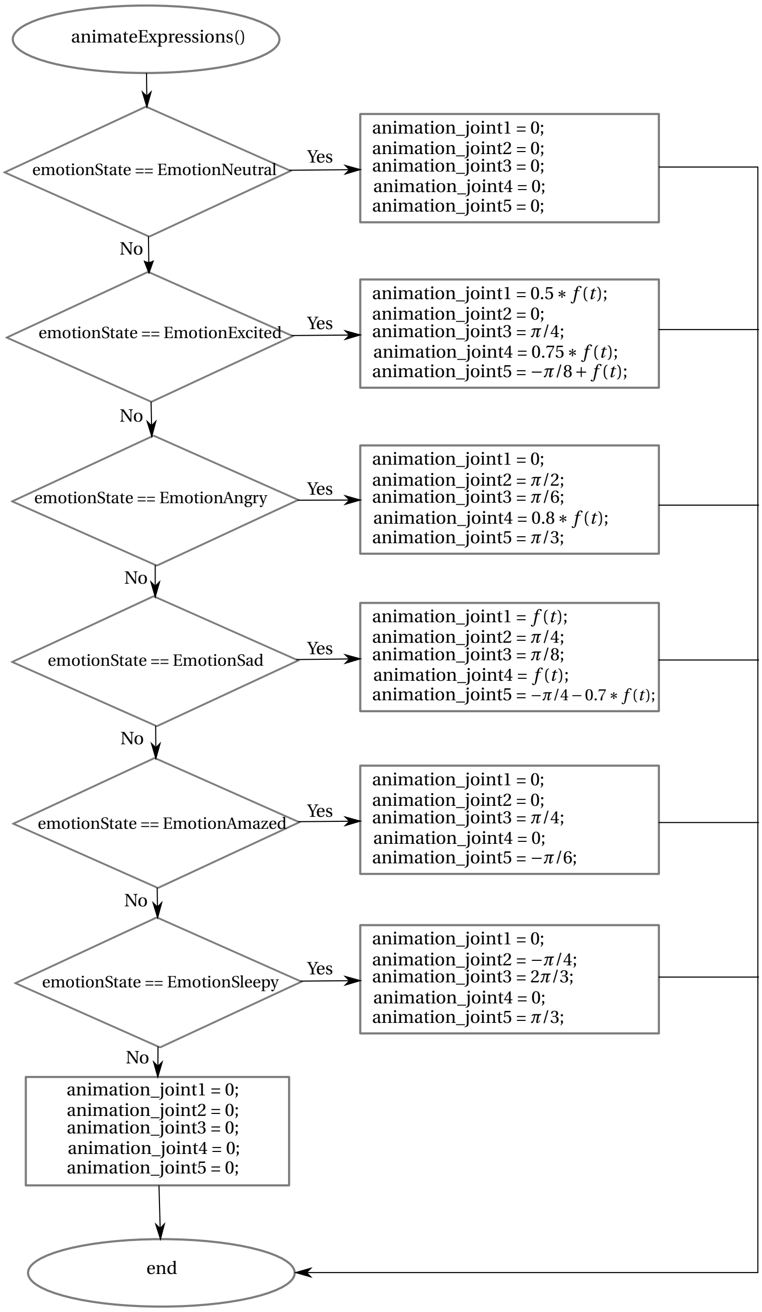

Figure B.1: Flow chart of the animateExpressions() function.

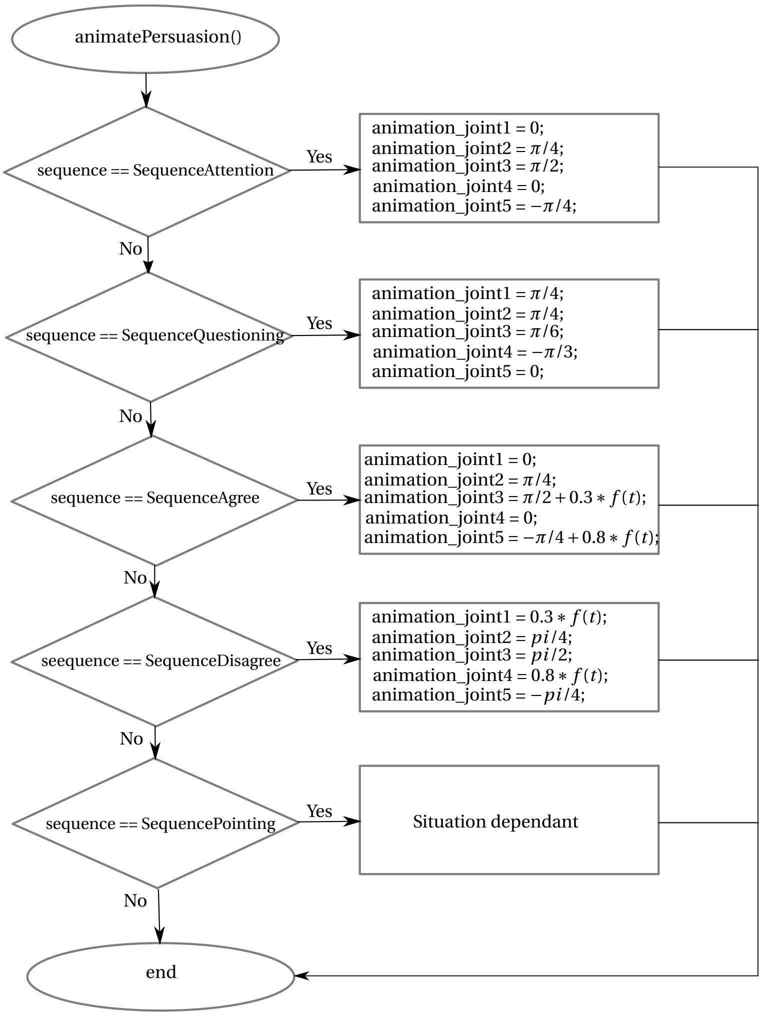

Figure B.2: Flow chart of the animatePersuasion() function.

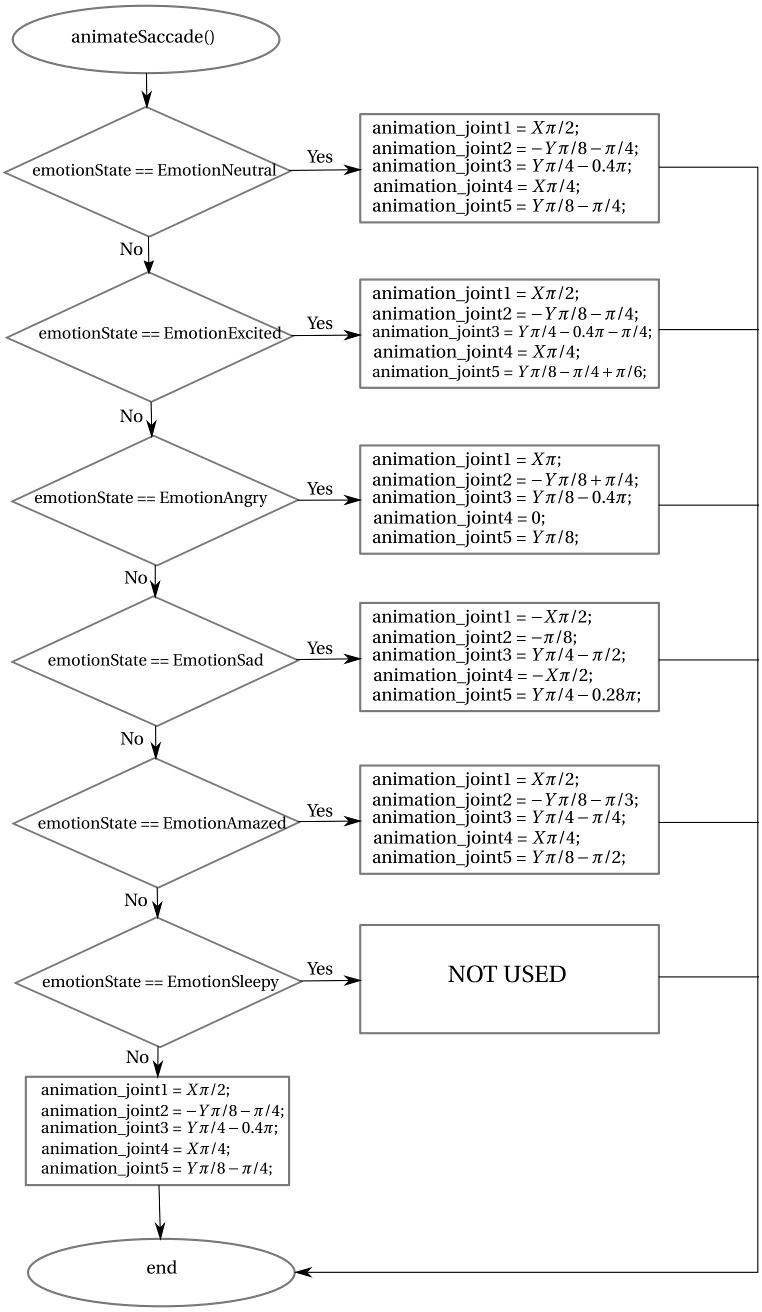

Figure B.3: Flow chart of the saccadeExpressions() function.

C Appendix 3 - ROS Computation Graph

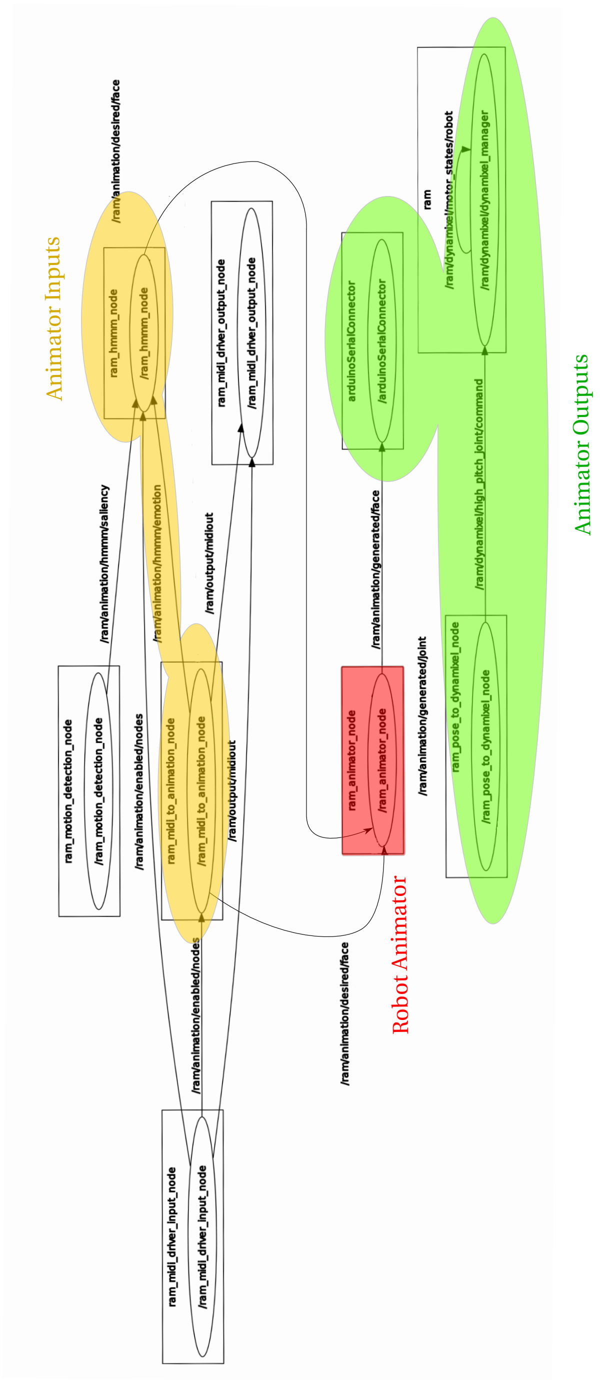

Figure C.1: Full ROS computation map of the persuasive social robot

D Appendix 4 - Joint angular position

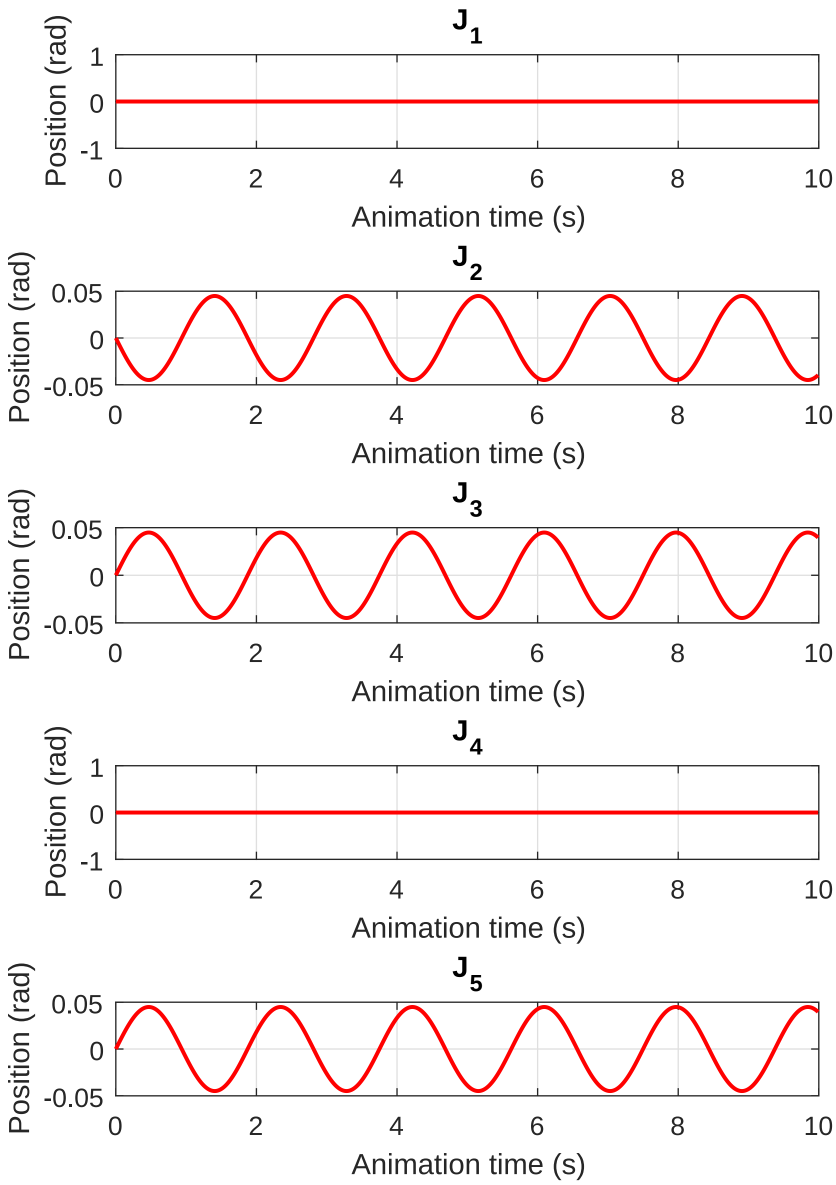

Figure D.1: 'Neutral' joint position.

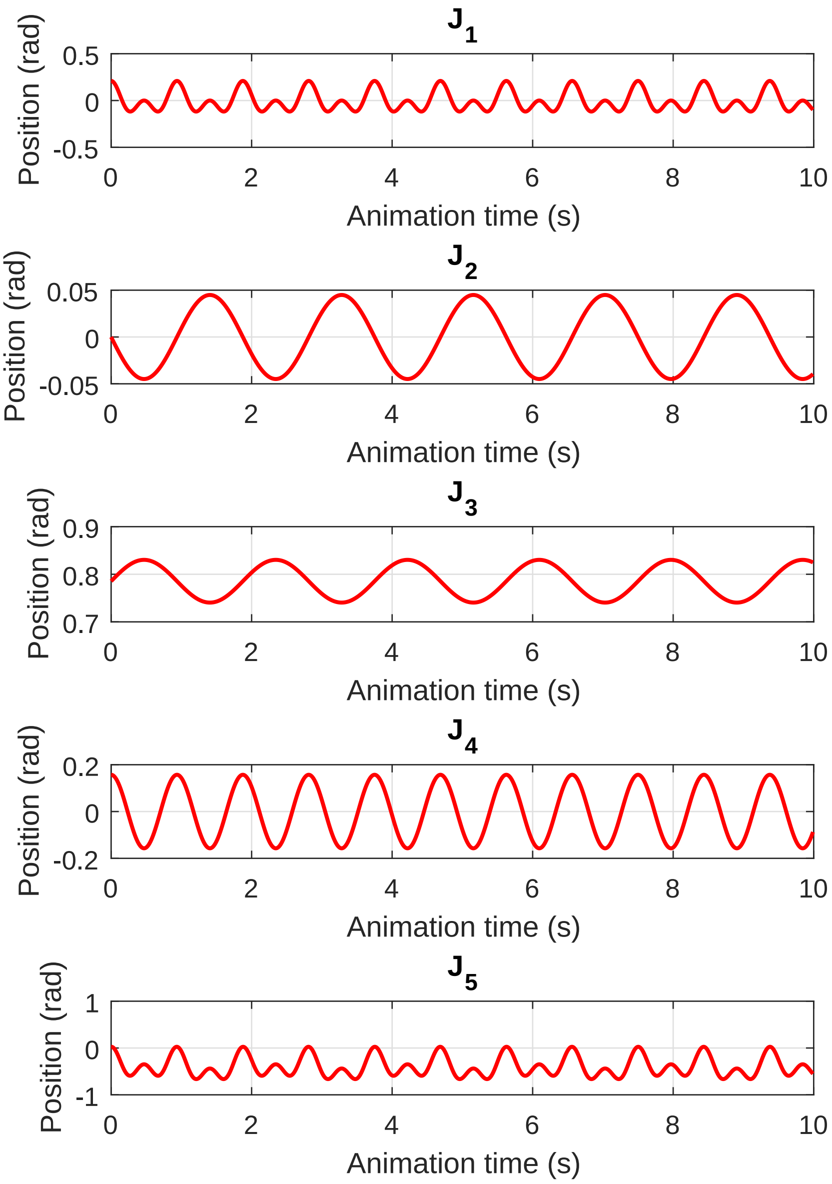

Figure D.2: 'Happy' joint position.

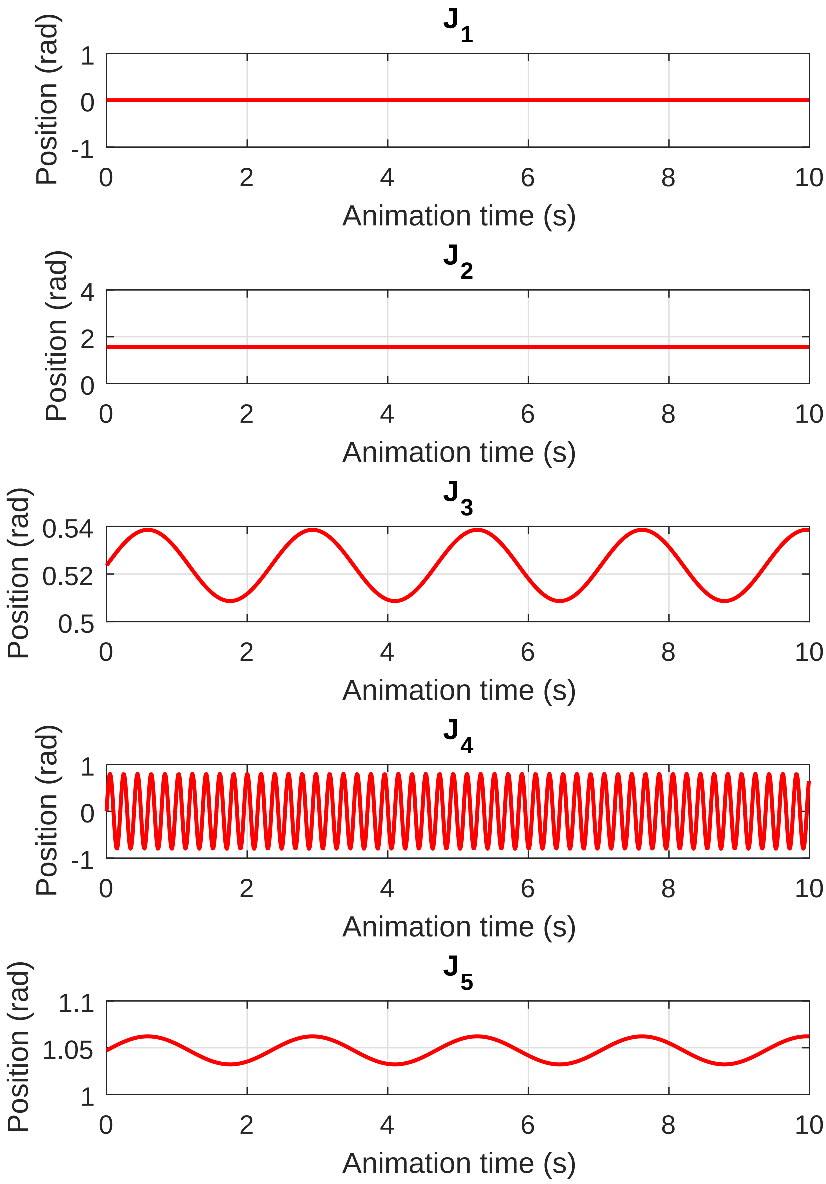

Figure D.3: 'Angry' joint position.

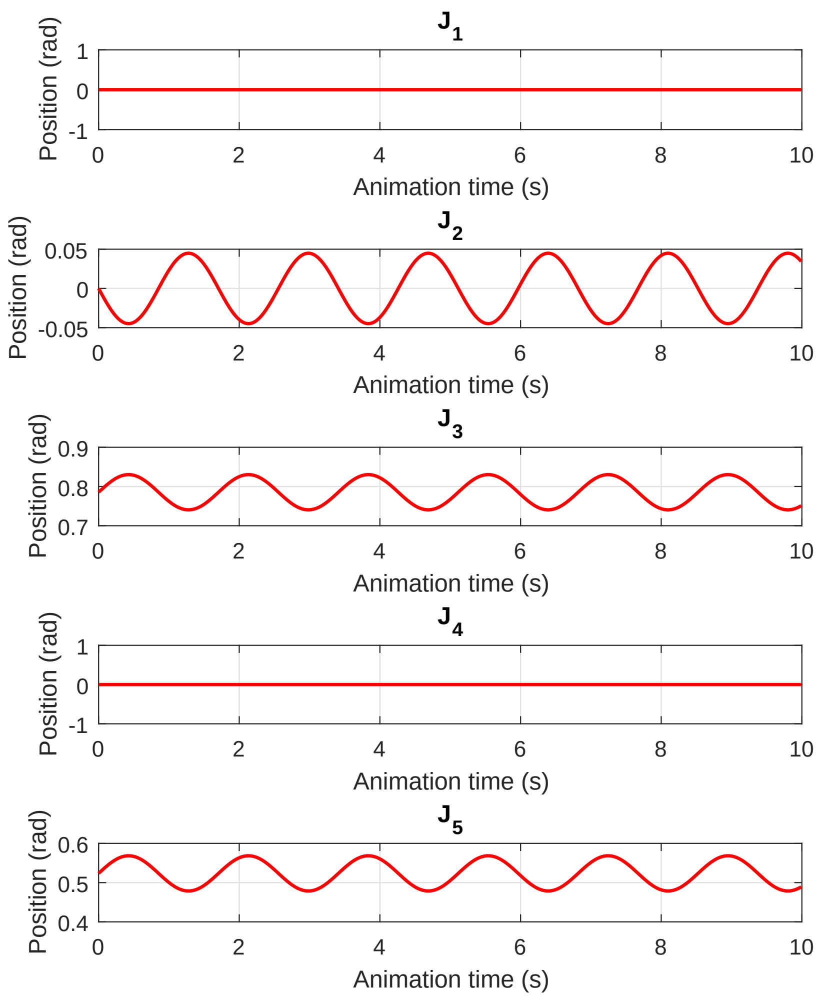

Figure D.4: 'Amazed' joint position.

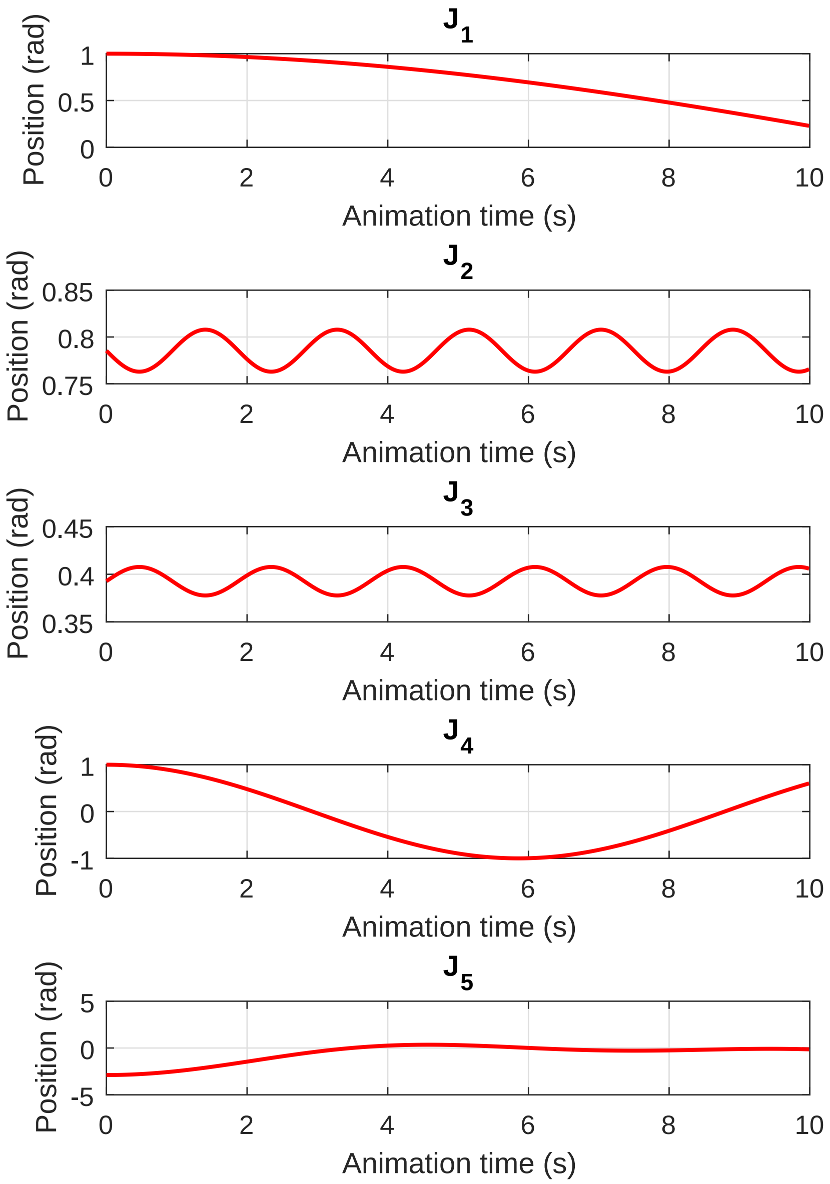

Figure D.5: 'Sad' joint position.

E Appendix 5 - Questionnaire for Test 1

UNIVERSITY OF TWENTE.

RAM

Questionnaire.-

Age: ______. Gender: F / M.

1. When arriving to the desk, which was the first element to catch your attention?
   a. The video game.
   b. The plant.
   c. The desk light.
   d. The red and green buttons box.
   e. Other. Explain: ______________________________________.

2. Before start playing with the video game, did you feel tempted to press at least one of the buttons (Red and Green) at your right?
   a. Yes.
   b. No.

3. Did the robot attract your attention while playing?
   a. Yes.
   b. No.

4. Did you fell the robot was annoying you?
   a. Yes.
   b. No.

5. What did you fell when pressing either the red or green button when indicated by the robot?
   a. I felt like I was helping the robot.
   b. I felt annoyed to press the button.
   c. I pressed the buttons, but I didn't feel anything.
   d. I didn't press any of the buttons.

6. How did you feel having the robot nearby? Encircle the answer that fits your experience.
   a. Comfortable, I didn't mind having the robot around.
   b. Uncomfortable, I didn't like being near the robot.

7. How does the robot look? Encircle only one answer that fits your experience.
   a. The robot looks nice/cool.
   b. I don't like or dislike how the robot looks. I don't care.
   c. The robot is somewhat ugly/scary.

8. From each of the next 6 items, choose only one option (either A or B) that better describes the robot:

Item	Option A	Option B
1	Good natured	Irritable
2	Cheerful	Sad
3	Tense	Relaxed
4	Calm	Nervous
5	Good	Bad

Figure E.1: Questionnaire used in Test 1

F Appendix 6 - Log of events of Test 1

Design Lab, University of Twente. 6/12/17

This log describes the relevant events during the interaction between the user(s) and the Desk-Light social robot.

Participant #1 - Lenght of footage: 0:04:07

- **No data could be retrieved due to bad camera frame and focus**

Participant #2 - Lenght of footage: 0:05:58

- 0:00:00 - Participant begins playing Super Mario
- 0:00:27 - Participant looks at the robot. The robot is in straight position shaking its body.
- 0:01:04 - Participant loses another life and turns the head toward the robot. The robot is nodding.
- 0:01:20 - Participant turns the head toward the robot while the Game Over screen appears. The robot is disagreeing.
- 0:01:42 - The robot dances to catch the participant's attention. No response from the participant.
- 0:02:02 - Participant takes a 'frustrated' look to the robot during the 'life lost cut scene.
- 0:02:06 - Participant looks at the robot. The robot is pointing the button box.
- 0:03:11 - Participant takes a look to the robot during the 'life lost' cut scene.
- 0:03:54 - Participant takes a look to the robot.
- 0:04:18 - Participant takes a look to the robot. The robot is changing posture to straight position.
- 0:05:02 - End of the test.

Participant #3 - Lenght of footage: 0:04:53

- 0:00:00 - Participant begins playing Super Mario.
- 0:00:19 - Participant looks at the robot. The robot is standing straight.
- 0:00:44 - Participant takes a long look at the robot during a 'level cleared' cut scene. The robot dances and points the button box.
- 0:00:53 - Participant takes another look to the robot while the game is starting. The robot is standing straight.
- 0:00:57 - Participant takes a look to the robot during a 'next level' cut scene. The robot points the button box.
- 0:02:15 - Participant looks again toward the robot during a 'life lost' cut scene. The robot is disagreeing and pointing the button box.
- 0:02:47 - Participant takes another look at the robot. The robot stands straight.
- 0:02:53 - Participant looks at the robot during a 'level cleared' cut scene. The robot is pointing the button box. The participant makes a 'guessing' expression, but there is no interaction with the button box.
- 0:03:03 - Participant takes a fast glimpse of the robot. The robot is standing straight.
- 0:03:46 - Participant looks at the robot during a 'life lost' cut scene. The robot is moving from straight position to neutral state.
- 0:04:20 - Participant looks at the robot during a 'level cleared' cut scene. The robot is pointing to the button box.
- 0:04:31 - End of the test.

G Appendix 7 - Log of events of Test 2

Design Lab, University of Twente. 14/12/17

This log describes the relevant events during the interaction between the user(s) and the DeskLight social robot.

Footage #1 - Lenght of footage: 0:04:55 - Interactions: 2

- 0:00:30 - Two kids arrive to the setup. They immediately address the robot. One of the kids waves his hand to say hello to the robot.
- 0:00:51 - The robot points to the red button. No response from the kids.
- 0:00:55 - The robot points to the red button again. The kids press the red button.
- 0:01:02 - The robot dances due to the response of the kids. The kids dance with the robot.
- 0:01:15 - The robot points to the green button.
- 0:01:16 - The kids press the green button.
- 0:01:19 - The robot dances and the kids dance with it.
- 0:01:39 - One of the kids press the green button without being asked.
- 0:01:44 - The robot shows the disagreeing cue.
- 0:01:51 - The robot points to the green button. The kids press the green button.
- 0:02:24 - The robot points to the red button. The kids press the red button.
- 0:02:53 - The robot points to the red button. The kids press the red button.
- 0:03:46 - The robot points to the red button. The kids press the green button to evaluate the response of the robot.
- 0:03:50 - The robot shows the disagreeing cue.
- 0:03:52 - The robot points to the red button. The kids press the red button.
- 0:03:53 - The robot dances and the kids dance with it.
- 0:04:51 - The kids leave. End of the interaction

Footage #2 - Lenght of footage: 0:03:07 - Interactions: 1

- 0:00:01 - One kid arrives hesitating at the setup.
- 0:00:27 - The kid approaches to the robot from the side. The child seems shy.
- 0:00:42 - The robot points the green button. No response from the kid.
- 0:01:00 - The robot points the green button. No response from the kid.
- 0:01:05 - The robot points the green button. No response from the kid.
- 0:01:16 - The robot points the green button. No response from the kid.
- 0:01:32 - The robot points the green button. No response from the kid.
- 0:01:42 - The robot points the green button. No response from the kid.
- 0:02:09 - The robot points the green button. No response from the kid.
- 0:02:34 - The robot points the red button. No response from the kid.
- 0:02:42 - The kid moves in front of the robot. The robot points the red button. No response from the kid.
- 0:03:06 - The kid leaves. End of the interaction.

Footage #3 - Lenght of footage: 0:02:57 - Interactions: 1

- 0:00:01 - Two kids arrive at the setup.
- 0:00:06 - One kid says hello to the robot.
- 0:00:11 - The robot points the green button. No response from the kid.
- 0:01:07 - The robot points the green button. The kids press the red button.
- 0:01:20 - One of the kids press the green button without being asked. The robot shows the disagreeing cue.

- 0:01:28 - The robot points the red button. The kids press the green button. The robot shows the disagreeing cue.
- 0:01:42 - The robot points the red button. The kids press the green button. The robot shows the disagreeing cue.
- 0:01:59 - The robot points the red button. The kids press the red button. The robot dances.
- 0:02:28 - The robot points the green button. No response from the kid.
- 0:02:43 - End of the interaction.

Footage #4 - Lenght of footage: 0:02:55 - Interactions: 1

- 0:00:01 - Two kids arrive hesitating at the setup.
- 0:00:11 - The robot points the green button. The robot keeps pointing until a response.
- 0:00:20 - One of the kids press the green button. The robot dances.
- 0:00:40 - The robot points the green button. The kids say hello to the robot, but no button pressing.
- 0:00:56 - The robot points the green button. The kids press the green button after 5 seconds. Then the robot dances.
- 0:01:27 - The robot points the red button.
- 0:01:37 - The kids press the red button. The robot dances.
- 0:02:05 - The robot points the red button. The kids press the green button. The robot disagrees.
- 0:02:16 - The robot points the red button. No response from the kids.
- 0:02:46 - The kids leave. End of the interaction.

Footage #5 - Lenght of footage: 0:09:06 - Interactions: 4

- 0:00:01 - Two kids arrive hesitating at the setup. They look nervous in front of the robot.
- 0:00:30 - The robot points the green button.
- 0:00:34 - One of the kids press the green robot. The robot dances.
- 0:00:59 - One of the kids press the red button without being asked. The robot shows the disagreeing cue.
- 0:01:05 - The robot points the green button. The kids press the green button. The robot dances.
- 0:01:42 - The robot points the red button. The kids press the red button excitedly.
- 0:02:08 - The robot points the red button. The kids press the red button rapidly.
- 0:02:37 - The robot points the green button. The kids press the green button immediately.
- 0:02:55 - The kids leave. End of the interaction.
- 0:03:00 - Two different kids arrive to the setup. They look at the robot with curiosity.
- 0:03:27 - The robot points the green button. One of the kids pets the robot, but no button pressing.
- 0:03:46 - The robot keeps pointing the green button. One of the kids press the red button. The robot disagrees.
- 0:03:52 - The robot keeps pointing the green button. One of the kids press the red button. The robot disagrees. The kids laugh at the robot's response.
- 0:04:01 - The robot keeps pointing the green button. One of the kids press the green button immediately, racing against the other kid. The robot dances. Both kids dance with the robot.
- 0:04:12 - One of the kids press the green button without being asked.
- 0:04:21 - The robot points the green button. The kids press the green button and dance with the robot.
- 0:04:37 - One of the kids press the red button without being asked. The robot disagrees.
- 0:04:50 - The robot points the red button.
- 0:04:55 - The kids press the green button. The robot disagrees.
- 0:04:50 - The robot points the red button. The kids press the red button. The kids dance with the robot.
- 0:05:25 - The kids leave. End of the interaction.
- 0:05:32 - Two other kids arrive hesitating in front of the robot.
- 0:05:33 - One of the kids press the red button without being asked. The robot disagrees.

- 0:05:37 - One of the kids press the green button without being asked. The robot disagrees.
- 0:05:41 - The robot points the green button. The green button is pressed immediately. The robot dances. The kids play with the robot.
- 0:06:04 - The robot points the green button. The green button is pressed immediately. The robot dances.
- 0:06:16 - The kids press the buttons several time without being asked. It seems that they are testing the robot's response.
- 0:06:28 - The robot points the red button. The kids press the green button. The robot disagrees.
- 0:06:44 - The kids leave. End of the interaction.
- 0:06:47 - Another kid stands in front of the robot and observes it.
- 0:07:17 - The kid presses the green button without being told. At that exact moment, the robot points the green button.
- 0:07:18 - The robot disagrees as a late response of the puppeteer.
- 0:07:26 - The robot points the green button. The kid was prepared to press the indicated button as expecting the robot to show the cue. The green button is pressed and the robot dances.
- 0:07:50 - The robot points the red button. The kid press the button immediately and the robot dances.
- 0:08:20 - The kid crouches to observe the color light better, trying to anticipate the next cue of the robot.
- 0:08:43 - The robot points the green button. The button is pressed immediately and the robot dances.
- 0:08:58 - The kid leave. End of the interaction.

Footage #6 - Lenght of footage: 0:08:31 - Interactions: 3

- 0:00:01 - One kid arrives shyly at the setup.
- 0:00:13 - The robot points the green color. No response from the kid.
- 0:00:36 - The robot tries again and points the green color. The kid press the green button and steps back. The robot dances.
- 0:00:50 - A second kid joins the first one. The new kid stands in front of the robot.
- 0:01:03 - The robot points the red button.
- 0:01:08 - The first kid press the red button. The robot dances.
- 0:01:14 - One kid presses the green button without being asked. The robot disagrees.
- 0:01:18 - The same kid (of the previous entry) presses the red button without being asked. The robot disagrees.
- 0:01:20 - One kid keeps pressing buttons without being asked.
- 0:01:46 - The robot points the red button. The red button is pressed and the robot dances.
- 0:02:04 - The kids keep pressing buttons arbitrarily.
- 0:02:20 - The robot points the green button. The green button is pressed and the robot dances.
- 0:02:40 - The kids keep pressing buttons as playing with bongos.
- 0:02:56 - The robot points the green button. One kid presses both buttons.
- 0:03:00 - A third kid arrives at the setup.
- 0:03:33 - The robot points the green button. The second kid presses the green button happily and the robot dances. The first kid leaves.
- 0:03:40 - Buttons are being pressed happily and arbitrarily.
- 0:04:02 - Second kid leaves. The third kid stays to interact with the robot.
- 0:04:15 - The robot points the red button. The kid presses the red button and the robot dances.
- 0:04:30 - The kid presses the green button without being asked. The robot disagrees.
- 0:04:44 - The robot points the green button. The kid proceeds to press the green button, making the robot dance.
- 0:05:14 - Another kid arrives to take a look at the robot, then leaves.
- 0:05:19 - The robot points the red button. The kid steps back and analyses the situation.
- 0:05:29 - While the robot is pointing the red button, the kid decides to press the green button. The robot dances due to a mistake of the puppeteer.
- 0:05:52 - The buttons are pressed without asking to test the responsiveness of the robot.
- 0:05:54 - The robot points the green button. The kid presses the red button.

- 0:06:10 - The robot points the green button. The green button is pressed and the robot dances.
- 0:06:50 - The robot points the green button. The green button is pressed and the robot dances.
- 0:08:03 - The kid leaves. End of interaction.

Footage #7 - Lenght of footage: 0:02:52 - Interactions: 1

- 0:00:01 - One child arrives to the setup.
- 0:00:03 - The robot points the green button. The green button is pressed immediately. The robot dances.
- 0:00:18 - The kid looks at the desk light shade with curiosity.
- 0:00:19 - The robot nods in agreement. The kid laughs.
- 0:00:26 - The robot points the red button. The red button is pressed immediately.The robot dances.
- 0:00:41 - The kid presses the green button unsolicited. The robot shakes its body as disagreement.
- 0:00:47 - The robot points the green button. The green button is pressed immediately. The robot dances.
- 0:00:59 - The robot nods in agreement. The kid mimics the robot movements with the head.
- 0:01:02 - The kid places a hand over the button box to anticipate the next command from the robot.
- 0:01:09 - The robot points the red button. The kid presses the red button in response. The robot dances again and the kid smiles.
- 0:01:33 - The robot points the green button. The kid presses the green button immediately. The robot dances.
- 0:01:47 - The robot stands in straight position. The kid stares at the robot.
- 0:01:52 - The robot points the red button. The kid responds by pressing the red button. The robot dances and the kid smiles.
- 0:02:04 - The kid is distracted by another passing by child. The passing by child stays.
- 0:02:16 - The first kid explains the mechanics of the robot to the new child.
- 0:02:30 - The new child leaves. The fist kid observes the robot with curiosity.
- 0:02:42 - The kid leaves. End of interaction.

Footage #8 - Lenght of footage: 0:01:00 - Interactions: 1

- 0:00:01 - One child arrives to the setup and presses both buttons without being asked. The robot shakes the body disagreeing.
- 0:00:13 - The robot points the green button. The green button is pressed immediately. The robot dances and nods in agreement.
- 0:00:22 - The robot points a red button. The red button is pressed by the kid. The robot dances.
- 0:00:40 - The kid presses both buttons without being asked. The button disagrees.
- 0:00:46 - The robot points the green button. The green button is pressed immediately.
- 0:00:50 - The kid leaves. End of interaction.

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